REVIEW AND ANALYSIS OF OCEAN ENERGY SYSTEMS DEVELOPMENT AND SUPPORTING POLICIES

A report by AEA Energy & Environment on the behalf of Sustainable Energy Ireland for the IEA's Implementing Agreement on Ocean Energy Systems

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EXECUTIVE SUMMARY

Ocean energy technologies, including ocean wave, tidal current, ocean thermal energy conversion (OTEC) and salinity gradient, are at the early stages of development compared with other, more well-established renewable and conventional generation technologies.

The International Energy Agency's Implementing Agreement on Ocean Energy Systems commenced in October 2001. The Agreement's mission is to enhance international collaboration to make ocean energy technologies a significant energy option in the medium term future.

In 2003, under Annex 1 of the Agreement, a report was published which presented the status and priorities for wave and tidal current energy research, development and demonstration (RD&D). This report reassesses the status of ocean energy RD&D in 2006 and examines policies that impact on development, as well as services and facilities which support RD&D, and the barriers to progress.

This study has identified 81 individual ocean energy concepts which are currently being developed. These include 53 ocean wave technologies, 25 tidal current devices, one OTEC system and two salinity gradient concepts.

There has been a significant growth in the number of devices being pursued since 2003. Many more countries are now active in ocean energy RD&D. Activity is concentrated in Europe and North America. Some research projects have been discontinued as initial results showed that certain technologies would not be commercially viable in future market conditions.

The current development status of ocean energy technologies is varied. There are a relatively high number of emerging designs at the conceptual stage, several of which have advanced to detailed designs. Many device developers have constructed more advanced part-scale models and are undertaking simulated ocean testing. Several prototypes are now undergoing sea trials at full-scale or near full-scale. Only one device developer is involved in the demonstration of several devices in a pre-commercial farm, although other such projects have been proposed.

There is a wide range of ocean wave and tidal stream devices being researched, showing that RD&D is far from producing optimum design solutions. As yet, the level of understanding gained through demonstration is not sufficiently developed to identify which schemes will perform in the harsh marine environment as predicted and prove the most cost-effective.

Growth is further restricted by uncertainties surrounding the grid connection of demonstration projects, insufficient understanding of the environmental impacts, and a lack of collaboration and sharing of intellectual property between developers. Progress is also limited by the absence of guidelines and standards that enhance project development, evaluation, testing and comparability. This will better enable stakeholders, such as policy-makers, electricity network companies and investors, to select the technologies which meet their needs.

Generally, government funding for ocean energy RD&D is growing. Several RD&D programmes supported by governments and organisations are currently funding the development of ocean energy technologies. The increasing trend in the number of projects and the recent launch of dedicated RD&D schemes indicate that government expenditure will continue to increase provided RD&D objectives are met.

Importantly, as several technologies are nearing the market deployment and pre-commercial stage, some governments are reacting by proposing market support mechanisms to cover the current cost gap, and consenting arrangements to accelerate the rate of deployment while advancing industry learning and improving cost competitiveness.

To date there has not been sufficient demonstration of full-scale prototypes to prove that the technologies work. This is fundamental and the key barrier preventing deployment of ocean energy technologies. Developers must demonstrate their devices by establishing actual technical performance and the cost of generation, as well as proving availability, reliability and the survivability of concepts, and demonstrate these by publishing results. This obstacle must be tackled to ensure that RD&D progresses to the pre-commercial stage of demonstrating multiple devices in farms.

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1 INTRODUCTION

Sustainable Energy Ireland (SEI) has commissioned AEA Energy & Environment to perform a review and analysis of ocean energy policies and technology developments on behalf of the International Energy Agency's Implementing Agreement on Ocean Energy Systems.

Ocean energy systems are technologies which utilise energy from the earth's oceans. This report assesses ocean wave and tidal current technologies. Ocean thermal energy conversion and salinity gradient technologies are also briefly covered. Tidal barrage systems are not examined.

This report analyses the research, development and demonstration (RD&D) of ocean energy systems in terms of the four aspects outlined below:

> Section 2: Current status of ocean energy systems RD&D.
> Section 3: Policies and support mechanisms which impact on development.
> Section 4: Services and facilities which provide practical support for RD&D.
> Section 5: Common barriers to progress and possible solutions.

The trends and correlations between development, policy and support are identified. Where possible, links between common policy and development trends are identified.

This study focuses on the countries that have signed the International Energy Agency's Implementing Agreement on Ocean Energy Systems (IEA OES). Other IEA and non-IEA member countries, where ocean energy systems are being developed, are also analysed.

The study identified as many technology projects as possible using various techniques:

> Analysis of questionnaires submitted by the delegate members of the IEA OES.
> AEA Energy & Environment's own ocean energy publications library and resources.
> Additional research and review of technology web sites.

Key organisations and device developers provided input on technologies. Information reporting the current status of RD&D (based on developers' own claims), results of testing and funding sources were gathered. Effort has been made to identify all technologies in development[1].

Information on policies which support and impact on ocean energy RD&D were obtained from a variety of sources, including the IEA OES member delegates, IEA publications and the IEA's Global Renewable Energy Policies and Measures Database[2]. Information on services and facilities which support RD&D was also gathered.

[1] Projects in non-IEA countries may have been overlooked owing to the lack of accessible information.
[2] The IEA's Global Renewable Energy Policies and Measures Database: http://renewables.iea.org

1.1 Ocean energy resource

The oceans contain a huge amount of energy that can theoretically be exploited for generating useful energy. Energy from changes in salinity, thermal gradients, tidal currents and from ocean waves can be used to generate electricity using a range of different technologies currently in development. The estimated global resource and range of technologies are summarised in Table 1.1.

Table 1.1. Types of ocean energy and technologies, plus estimated resource[3].

Ocean energy type	Technology types	Estimated global resource
Ocean wave	Attenuator, Collector, Overtopping, OWC, OWSC, Point absorber, Submerged pressure differential, Terminator, Rotor	8 000-80 000 TWh/year
Tidal current	Horizontal/Vertical-axis turbine, Oscillating hydrofoil, Venturi	800+ TWh/year
Salinity gradient	Semi-permeable osmotic membrane	2 000 TWh/year
OTEC	Thermo-dynamic ranking cycle	10 000 TWh/year

1.1.1 Ocean wave

Ocean wave energy is the energy occurring from movements of water near the surface of the sea in an oscillatory or circular process that can be converted into electricity. Waves are a function of the energy transfer effected by the passage of wind over the surface of the sea. The distance over which this process occurs is called the 'fetch'. Longer fetches produce larger, more powerful waves, as do stronger winds and extended periods of wind.

1.1.2 Tidal current

Tidal current energy is energy contained in naturally occurring tidal currents which can be directly extracted and converted into electricity. Strong tidal currents are most frequently found near headlands and islands. These retard the progress of the tidal bulge as it moves around the earth, leading to head differences that can only be equalised by a flow of water around and between the land features. It is this flow that constitutes the tidal current. Energy can be extracted using devices that move in response to the forces the current exerts, and use this movement to drive an electrical generator. (Tidal current is also referred to as tidal stream.)

1.1.3 Ocean thermal energy conversion

Ocean thermal energy conversion (OTEC) is based on drawing energy from the thermal gradient between surface water temperature and cold deep-water temperature, by use of a power-producing thermodynamic cycle. A temperature difference of 20°C (from surface to approximately 1 km depth) is commonly found in ocean areas within 20° of the Equator. These conditions exist in tropical areas, roughly between the Tropic of Capricorn and the Tropic of Cancer.

[3] Source: IEA, 2006.

1.1.4 Salinity gradients

Salinity gradient technology can take two forms. The first, commonly known as the solar pond approach, involves the application of salinity gradients in a body of water for the purpose of collecting and storing solar energy. Large quantities of salt are dissolved in the hot bottom layer of the body of water, making it too dense to rise to the surface and cool, causing a distinct thermal stratification of water that could be employed by a cyclic thermodynamic process similar to OTEC. The second application of salinity gradients (and the one most commonly referred to when describing electricity generation from salinity gradients) takes advantage of the osmotic pressure differences between salt and fresh water. The exploitation of the entropy of mixing freshwater with saltwater is often facilitated by use of a semi-permeable membrane, resulting in the production of a direct electrical current.

1.2 Development of ocean energy technology

Since the oil price rises of the 1970s, the general global trend in government RD&D budgets for renewable energy and ocean energy RD&D increased significantly and peaked in the 1980s, resulting in several billions of US dollars being spent on energy RD&D. Overall, there has been a resurgence in RD&D of ocean energy technology since the 1990s[4].

This study has identified 81 technology development projects at various stages of RD&D.

In parallel with the expected growth in the RD&D of ocean energy technology in the 21st century, several IEA member states offer support for ocean energy research through a range of energy policies. Advances in RD&D (eg the demonstration of several full-scale devices) have motivated a number of governments, notably those with large ocean energy resources, to introduce policies dedicated to supporting the demonstration and deployment of arrays of multiple ocean energy systems.

These include the following key headline policy developments:

- In 2005, the Portuguese Government agreed a feed-in tariff with a wave energy developer of EUR 0.23/kWh.
- The US Energy Act of 2005 officially recognises ocean energy technologies as renewable technologies which are open for production and investment tax credits.
- In 2006, the British Government launched the Wave and Tidal Stream Energy Demonstration Scheme which will provide capital grants and revenue support to demonstrate pre-commercial farms of ocean energy systems in the UK.
- The Irish Government launched its national ocean energy RD&D strategy in early 2006. The first phase of the plan is underway and will demonstrate and evaluate several near full-scale wave energy prototypes at sea.
- The IEA Implementing Agreement on Ocean Energy Systems, which promotes international research collaboration, has attracted greater participation. Contracting parties include the European Commission, Canada, Denmark, Ireland, Japan, Portugal, the United Kingdom and the United States of America (which joined in 2005). Several other countries, including France, Belgium, China, Brazil and South Africa, have expressed interest.

[4] Research into ocean wave technologies grew rapidly in the 1970s, however, success was limited and government funding reduced in the mid-1980s. Wave energy research saw a resurgence in activity during the 1990s, with the installation of several full-scale shoreline devices and the testing of a number of offshore device prototypes. Tidal current developments started in the 1990s.

The number of ocean energy concepts being researched has increased significantly in recent years and several devices have now been demonstrated at sea, either at part or full-scale. These developments have been aided by increased government RD&D support and the provision of dedicated RD&D support services which offer expertise, knowledge and facilities to aid the development of policy, technology and non-technical research. However, the long term prospects for ocean energy are still uncertain and several technical and economic barriers remain.

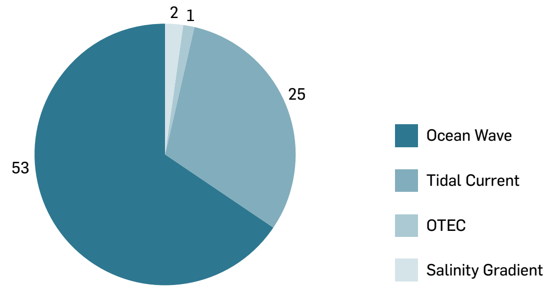
2 TECHNOLOGY DEVELOPMENT

This section presents the analysis undertaken on ocean energy technologies currently being researched, developed and demonstrated worldwide. General trends observed are described and the current development status is summarised. Key technical developments are highlighted. The technologies identified are listed in the Annex.

2.1 Research, development and demonstration of technology

Ocean energy technology is still regarded to be at the early stages of development compared to other, more well-established renewable and conventional generation technology. Historically, global research into ocean wave energy began in the 1970s; however, the majority of those technologies currently in development started in the 1990s. Development of tidal current technology began in the 1990s, although the number of RD&D projects has increased significantly over the last three years. OTEC technologies have been in development since the 1970s, but few research projects are on-going.

Figure 2.1. Total reported ocean wave, tidal current, OTEC and salinity gradient technologies in development in 2006.



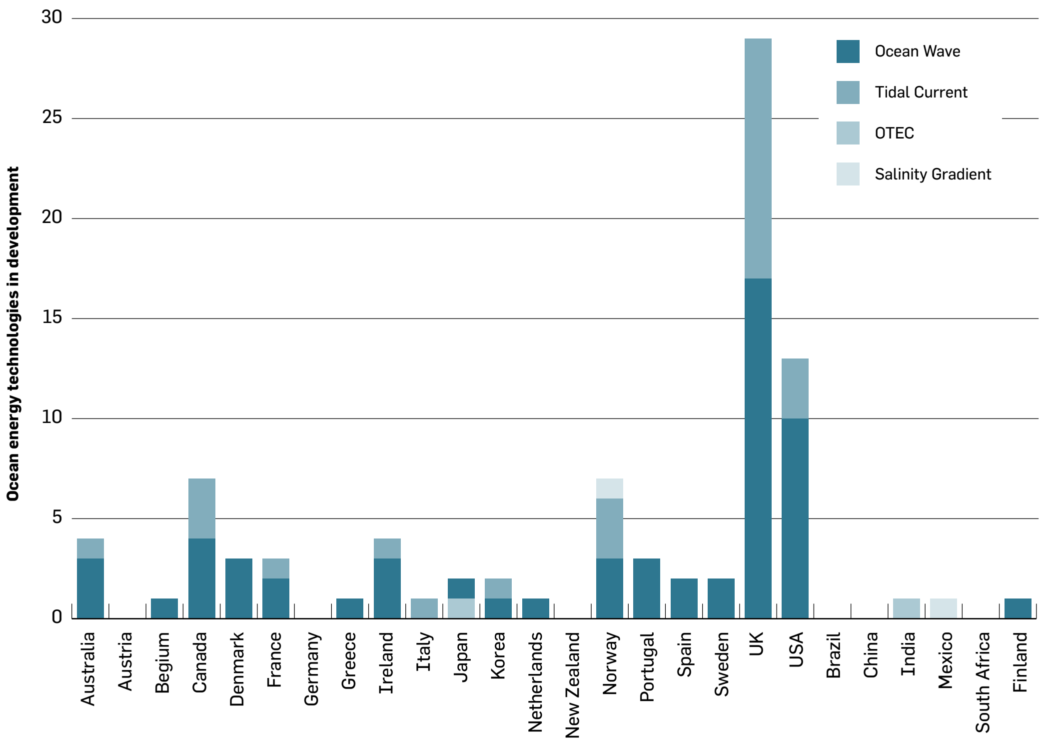
This study has identified 81 individual concepts currently in development[5]. These include: 53 reported ocean wave technologies in development; 25 tidal current projects; one OTEC system and two salinity gradient concepts (see Figure 2.1). The current number of ocean wave technologies in

[5] These figures do not include those technologies which have been discontinued owing to poor cost competitiveness. For example, after detailed design and testing, the EB Frond OWSC and the Stingray oscillating hydrofoil are no longer in development in the UK and likewise the Mighty Whale OWC device in Japan.

development is unsurprising given that wave energy is estimated to be the largest ocean energy resource available for exploitation (see Table 1.1). Also, compared to the other technologies, ocean wave is the most widely researched area. The current level of research in to OTEC technology is small in comparison to the significant amount of research undertaken between the 1970s and mid 1990s. Factors such as the predictability of tidal currents, the relatively large resource estimated in coastal waters of the key countries involved in RD&D, and the advanced development of similar turbine and component technologies (eg hydro, wind and marine technologies) have contributed to the significant growth in the development of tidal current concepts over the past five years. Research into generating electricity from salinity gradients is in its early stages and hence is limited. Based upon registered patents, hundreds of wave and tens of tidal current design concepts exist[6]. However, the number of concepts that are then designed in detail or become prototype technologies is limited, as shown by the number of developments identified in this study.

Ocean energy RD&D projects are in progress worldwide and their distribution is more concentrated in certain countries and continents, as shown in Figure 2.2[7]. The country with the highest number of technology projects is the United Kingdom (17 wave energy projects and 12 tidal current projects documented). The United States has the second highest number of projects in development (10 ocean wave and three tidal current). In Canada several RD&D projects are underway (four ocean wave and three tidal current). RD&D is on-going in Norway, where one salinity gradient, three tidal current and three wave projects are underway, and in Denmark, where three ocean wave concepts are being pursued. Technologies are also in development in several other countries. The highest

Figure 2.2. The ocean energy technology RD&D projects in March 2006.



[6] Source: Marine Energy Challenge, Carbon Trust.

[7] Figure 2.2 includes primary development projects underway in individual countries. Some technologies are being developed in more than more country, therefore the total number of projects is more than the total number of technologies in development outlined in Figure 2.1.

concentration of RD&D projects is located in Europe and North America. It should be noted that less is known of technology developments in countries that do not participate in the IEA OES and other non-IEA countries owing to a lack of accessible information. It is possible that other projects are on-going in these countries.

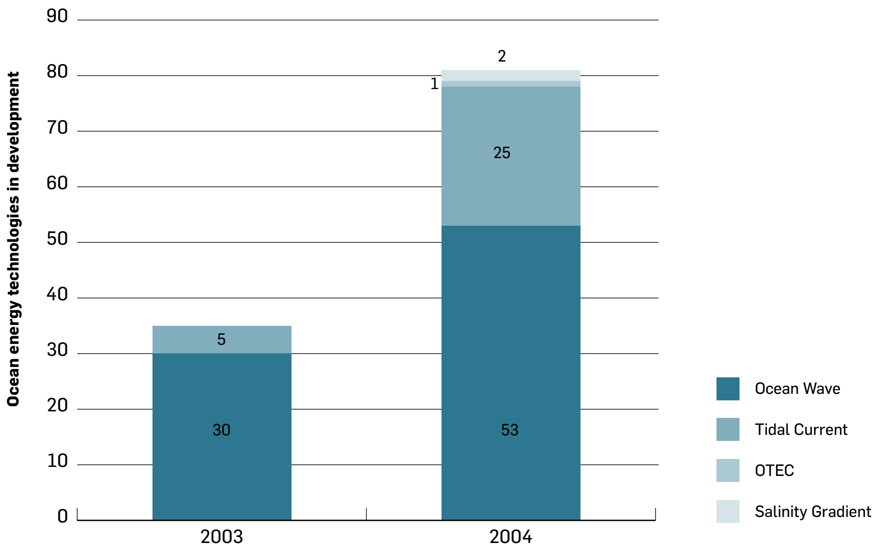
2.2 Development trends

Observations and development trends identified during the research and analysis are described below.

2.2.1 Recent increase in ocean energy RD&D

To establish whether the number of ocean energy technologies in development is growing, a comparison must be drawn with previously documented projects. The 2003 IEA OES Annex 1 Report[8] identified 35 ocean energy technologies. Comparing this figure with the latest project information gathered in this study, the number of projects has more than doubled in the last three years as shown in Figure 2.3. Most interesting has been the increased RD&D in tidal current technology, resulting in five times as many projects in 2006 than in 2003. Since 2003, research into OTEC has progressed in Japan, resulting in the installation of a full-scale prototype at sea off the coast of India. The development of technology that generates electricity from salinity gradients has been recognised in Norway. Notably, the number of projects has increased despite the fact that several devices are no longer being researched in 2006.

Figure 2.3. Ocean energy technologies currently in development compared to 2003.



2.2.2 Development teams

Typically, an ocean energy concept is developed by one of the types of team listed below:

> Small team of academics within a university department or research institute.
> Small start-up company.

[8] Wave and Marine Current Energy, Status and Research and Development Priorities, DTI, IEA, 2003. http://www.iea-oceans.org/

> Specialist equipment manufacturer.
> Large energy company monitoring and assessing the feasibility of concepts.
> Combination of the above within a consortium.

A pattern observed is the tendency for smaller developers to form partnerships with various companies, including:

> Engineering consultants.
> Energy generation and transmission specialist companies.
> Companies involved in the marine and offshore industry.

The benefit of incorporating additional specialist skills and experience into the development process accelerates the rate of development. This is the aim of technology acceleration policies. For example, device developers involved in the Carbon Trust's (United Kingdom) Marine Energy Challenge (MEC) claim the rate of development has been improved through these types of specialist collaboration.

2.2.3 Location and migration of RD&D

RD&D is not always confined to a single country. Some technologies have migrated from one country to another as the technology has been developed. A number of wave technologies have been designed in one country and demonstrated in other countries. For example, the AWS wave energy converter has been designed in the Netherlands and tested at sea in Portugal. There are plans for several device concepts developed in other countries to be demonstrated in multiple device arrays in the UK (eg the PowerBuoy point absorber wave farm proposed by Ocean Power Technologies Inc and the SEEWEC concept are planned be deployed at the proposed Wave Hub project).

The location of RD&D is influenced by several factors including:

> Availability of the human resource and skills required.
> Location of the appropriate R&D support facilities.
> Availability of financial support for RD&D in a country.

There has been an increase in the number of subsidiaries of overseas companies. For example, five of the eight wave developers supported under the MEC were subsidiaries of non-UK companies. This trend is evident in the UK due to the MEC, the Marine Renewables Deployment Fund[10] and subsidised grid infrastructure and connection (eg the European Wave Energy Centre and the Wave Hub concept).

International consortia have teams of researchers working on particular aspects of technology in different countries. For example, the SEEWEC point absorber and Seaflow tidal turbine part-scale model sea trial involves several parties from around Europe. These examples of international collaboration received grants from the European Union.

[9] The Carbon Trust's Marine Energy Challenge (United Kingdom) provided GBP 3 million of funding to accelerate the development of eight ocean energy projects.
[10] The DTI's Marine Renewables Deployment Fund (United Kingdom) has made GBP 50 million available to support the pre-commercial demonstration of multiple device arrays.

2.3 Current status of technology RD&D

The technologies currently in development are at various stages of RD&D, with some being more advanced than others. For the purposes of determining overall status, the stages of the ocean energy RD&D process have been defined in terms of the following activities:

> Concept design.
> Detailed design.
> Part-scale model testing – tank testing.
> Part-scale model testing – sea trials.
> Full-scale or near full-scale prototype demonstration – single device at sea.
> Full-scale prototype demonstration – multiple devices at sea.

These categories encompass the various approaches to RD&D applied by developers. They are also consistent with the ocean energy development and evaluation protocol proposed by the HMRC, University College of Cork[11]. The technologies identified were categorised into one of the above stages based upon claims from developers most advanced stage of RD&D being undertaken as of March 2006)[12].

Figure 2.4. Overall current development status of ocean energy technologies.

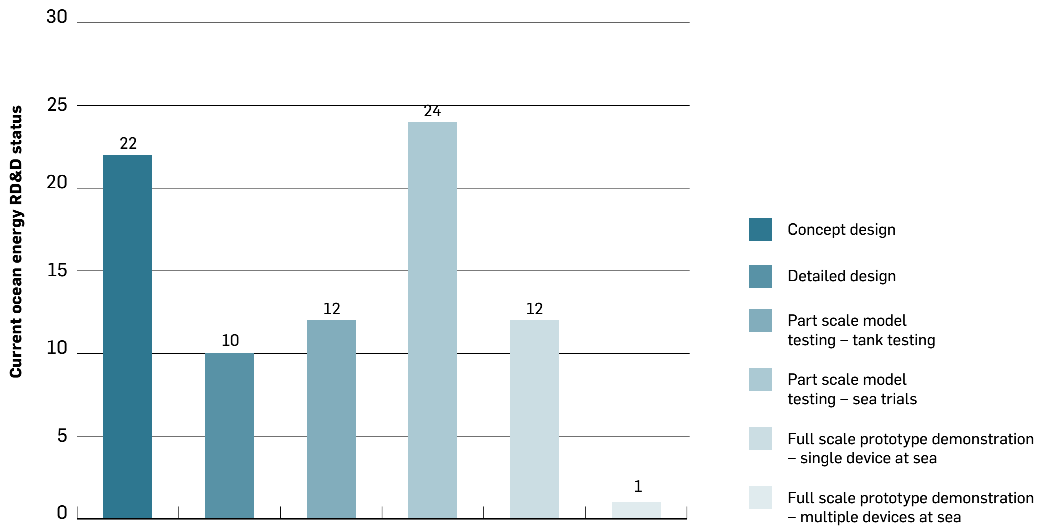


Figure 2.4 indicates that the current development status of ocean energy technologies is varied. There are a relatively high number of emerging designs at the conceptual stage (22 concepts). Several concepts have advanced to detailed designs (10 designs). Many device developers have constructed more advanced models and are performing simulated testing of part-scale models in wave, flume or tow tanks (12 concepts). Twenty-four part-scale prototypes are currently being tested at sea, and 12 prototypes are now undergoing sea trials at full or near full-scale. Ocean Power Delivery Ltd has manufactured and delivered three full-scale prototypes for the Aguçadoura wave farm demonstration project to be installed in Portugal in 2006.

[11] Source: http://www.marine.ie/industry+services/technology/renewable+energy/de(we)protocol.pdf

[12] This information was obtained via technology Web sites or by direct personal communication. Where possible, AEA Energy & Environment has corroborated these claims. It should be noted that summarising progress as a whole throughout the R&D sector based upon claims of developers might not be a precise reflection of actual development.

There are still several relatively new devices at the concept stage, indicating that the total number being developed is still growing. Generally, the greater the number of technology developments, the greater the level of competition within the sector. Increased competition should lead to better cost-competitiveness longer term, however the growing number of concepts in development at this stage also indicates that RD&D is not yet close to converging on an optimum design. This also highlights the technical uncertainty that is present within ocean energy development (explained in greater detail in section 2.4).

Twelve ocean energy developers claim to be at the full-scale demonstration phase. Few have so far completed testing or published results. Demonstration of any technology at full-scale is not simply a one-off activity. Examples of near full-scale demonstrations already undertaken have resulted in redesign followed by further testing[13]. It is likely that demonstration at full-scale may need to be repeated until satisfactory results are achieved.

No device developer has yet completed a demonstration of multiple full-scale devices in an array or pre-commercial farm. One wave farm project is underway, although other developments have been proposed.

Figure 2.5. Current development status of ocean energy technologies by country

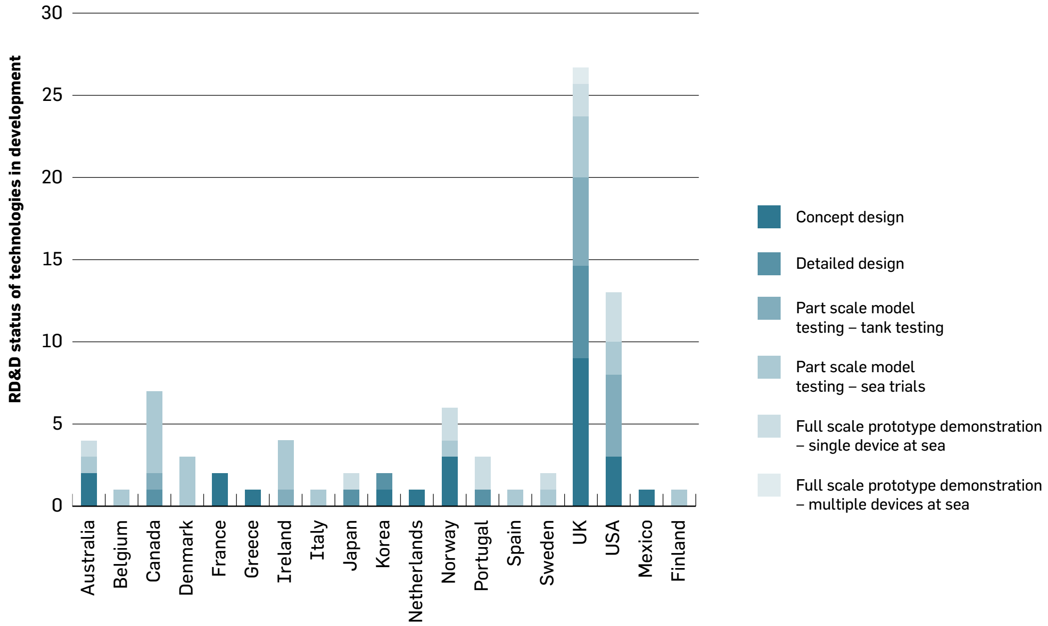


Figure 2.5 shows that development progress is varied across several countries with the most advanced activities located in the UK and USA. This progress is reflected by the recent policy developments concerning consenting procedures for demonstrations at sea in these countries (detailed in section 3.4) and public funding of an ocean testing facility in the UK.

[13] OPT redeployed a modified near full-scale prototype of its PowerBuoy in Hawaii in 2004 after initial testing. Also, Aqua Energy is planning a near full-scale demonstration in Denmark after the redesign of the AquaBuoy point absorber. Pelamis will also undergo further testing in 2006.

2.3.1 Ocean wave

Wave energy technology is currently the most researched area and, in comparison to tidal current, is the most advanced ocean energy technology based upon global development. Certain developers have claimed to be at the first-production model stage. However, full-scale demonstration of initial prototypes at sea is still on-going. Nine devices surveyed were in the process of being tested at full-scale (or near full-scale) at sea, with 26 developers testing part-scale models.

Progress can be gauged by reviewing a number of key developments as follows.

In May 2005, Ocean Power Delivery (OPD) Ltd (United Kingdom) secured a contract with the Portuguese utility Enersis to supply three Pelamis wave energy converters, each with a rated capacity of 750 kW. A letter of intent has been received to supply a further 28 machines subject to satisfactory performance. The first production model was manufactured in Scotland and delivered to Portugal in March 2006. All three machines will be delivered to the Port of Peniche where they will undergo final assembly prior to commissioning and installation later this year[14]. This development will be supported financially by a feed-in tariff of EUR 0.23 / kWh and is a significant step towards the market deployment of commercial ocean wave technology. This example of *market pull* demonstrates the impact of a market deployment support mechanism. It also indicates the level of subsidy required to make a wave energy generation project commercially viable, based on the current cost of electricity produced by the Pelamis machine.

In terms of testing, OPD completed 200 hours of full-scale, grid-connected demonstration at the EMEC test centre in Orkney (United Kingdom) in 2004, generating a peak power output of 190 kW[15]. Testing results have not been published. OPD plans to carry out further demonstration of the full-scale Pelamis prototype at EMEC in 2006.

Ocean Power Technologies (OPT) Inc (United States) has completed the redeployment of an improved PowerBuoy wave energy converter in 2004 under its contract with the US Navy at a US Marine Corps base in Hawaii. Because of its location on a naval base, OPT is not subject to licensing requirements though it must still comply with other environmental regulations, including preparation of an Environmental Assessment which has been completed. A separate demonstration project is in progress with the New Jersey Board of Public Utilities (NJBPU), resulting in a second prototype (rated at 40 kW) being installed in October 2005 off the coast of New Jersey. OPT is working with Iberdrola Renewables to develop a PowerBuoy demonstration array at Santona, off the northern coast of Spain. The project plan is to install one PowerBuoy followed by a further nine devices subject to performance (connected to the Spanish national grid). OPT is also planning a similar wave farm project with energy company Total in France[16].

Three separate wave farms are being planned for the proposed Wave Hub marine grid-connection concept which aims to connect arrays of multiple devices to the UK grid. Pelamis, PowerBuoy and SEEWEC wave energy devices have been short-listed for this pilot project. Current estimates put the cost of the proposed project at GBP 15 million[17] (the UK's South West Regional Development

[14] Source: http://www.oceanpd.com

[15] Source: http://events.sut.org.uk/past_events/040908/oceanpowerdelivery.pdf

[16] Source: http://www.oceanpowertechnologies.com/about.htm

[17] This is the estimate for the total cost of the facility. It does not include the capital expense of any wave energy conversion device connected to the sockets. Source: http://www.southwestrda.org.uk

Agency has already committed GBP 2 million of public funding to this project). An environmental impact assessment of the proposed site was initiated in 2005. The development could be significant as it would reduce the risk and cost associated with the grid-connection of initial arrays and help bridge the gap between RD&D and commercial deployment generation costs.

2.3.2 Tidal current

Overall, tidal current energy technology is not as widely researched as wave energy. However, the status of developments has advanced significantly in recent years. A number of developers have been or are currently undertaking testing of prototypes at sea. Based upon the projects surveyed during the analysis, five projects are at the full-scale or near full-scale prototype testing phase, and ten projects are at the part-scale prototype stage. The remaining ten devices are at the conceptual design stages.

In terms of the technology type, all but one of the tidal generators being tested at full-scale are using horizontal-axis turbines to capture the tidal current energy, the remaining one is a vertical-axis rotor type. As well as a range of rotary devices, other concepts at the earlier design stages are ducted Venturi choke systems, an oscillating hydrofoil system, and an air injected pressure amplifier device.

Several key device developments in the sector are described below.

Canada's first tidal current demonstration project is due to be installed at the Race Rocks Ecological Reserve in 2006, offshore of Vancouver Island in British Columbia. The project is a result of a partnership between Lester B. Pearson College of the Pacific, EnCana Corporation and Clean Current Power Systems Inc. The majority of the project is funded privately from the EnCana Environmental Innovation Fund which has provided CAD 3 million of private investment. The project is also supported by AMEC, Powertech Labs Inc, Triton Consultants Ltd, Oceanworks International, Xantrex Technology, and Robert Allan Ltd. The horizontal-axis, direct drive tidal turbine will provide power to an island that is currently supplied by a generator.

Marine Current Turbines Ltd (United Kingdom) was granted permission for a 1 MW device in Northern Ireland in 2005. This full-scale demonstration model will be grid-connected and function in both directions of the tidal flow (the prototype for the commercial production model). Utility company EDF is a partner, and the project is scheduled to operate from 2006 to 2007. The UK DTI has allocated a GBP 2 million grant to the project through the Technology Programme.

Verdant Power (United States) has redesigned its Gorlov tidal turbine design called the Kinetic Hydro Power System. The second phase of its three-phase tidal energy project in New York City's East River is underway. Verdant Power plans to install an array of six, 5-metre diameter rotor, grid-connected, axial-flow turbines, mounted on the river bottom in 2006. The authorities awarded special consent on a temporary basis provided the demonstration project sells no electricity commercially.

2.3.3 OTEC

A single OTEC project, developed by the Institute of Ocean Energy in Japan, has been identified. Demonstration is on-going of the full-scale plant (rated at 1 MW) which has been installed off the coast of India. The Japanese Government has provided USD 40 million of public funding to the Institute for OTEC research.

It is felt that one project cannot be taken as representative of the overall status of OTEC technology. Significant research has been carried out since the 1970s. However, current research into this technology is small in comparison, for example, the US Department of Energy invested approximately USD 250 million in OTEC research from the late 1970s until 1994 . Since then, there has been very limited investment in ocean technologies by the Department of Energy. OTEC is considered by some to be logistically near impossible to accommodate, not least because of the tremendous volumes of water which must be pumped over great distances. However, there may be some locations where it can be more viable due to favourable temperature differentials.

2.3.4 Salinity gradient

This study identified two salinity gradient projects. In Norway, a research project is underway, funded by the EU and sponsored by the Nordic power producer Statkraft. A number of part-scale salinity concepts have been installed at the seafront in the town of Sunndalsøra and in the SINTEF laboratory at Brattøra in Trondheim. The research is in collaboration with membrane developers in Germany, Finland and Portugal. It is the efficiency of membrane technology that is the key to a breakthrough in salinity energy. A separate research project is also underway in Mexico.

2.4 Current trends in technology type

The range of different types of ocean wave and tidal current concepts currently being developed has been analysed to establish the technical status of development and identify whether RD&D has produced optimum design solutions.

2.4.1 Ocean wave

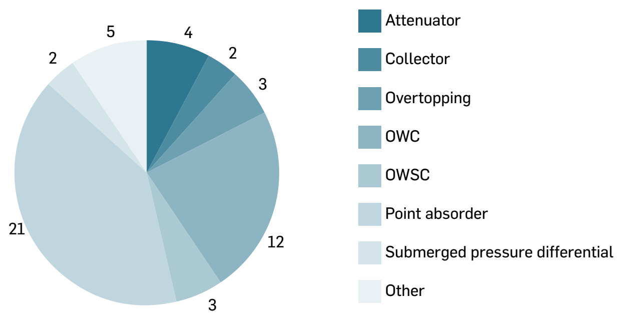
Fifty-three individual ocean energy technologies were identified in the previous section. The device characteristics of each concept were established and several modes of operation for wave energy devices identified. This report grouped the technologies into the classifications described in Table 2.1 below.

Table 2.1. Types of ocean wave energy generation technologies.

Technology type	Description
Attenuator	An attenuator is a long floating structure aligned in parallel with wave direction, which effectively rides the waves. Movements along its length can be selectively constrained to produce energy. It has a lower area perpendicular to the waves in comparison to a terminator, so the device experiences lower forces.
Collector	A collector is a floating device which captures waves to concentrate the energy into various power take-off systems.
Overtopping	An overtopping device is a wave surge/focusing device, and contains a wall over which waves topple into a storage reservoir. The reservoir creates a head of water, which is released through hydro turbines as the water flows back out to sea. An overtopping device may use collectors to concentrate the wave energy.
Oscillating Water Column (OWC)	An OWC comprises a partly submerged, resonantly tuned collector, open to the sea below the water surface and effectively containing air trapped above a column of water. This column of water moves up and down in sympathy with the wave movements, behaving like a piston, compressing and de-compressing the air. This is then channelled through an air turbine, usually a bi-directional 'wells' turbine making use of airflow in both directions, on the compression and decompression of the air.
Oscillating Wave Surge Converter (OWSC)	An OWSC is also a wave surge/focusing device, but extracts the energy that exists in waves caused by the movement of water particles within them. It comprises a near-surface collector mounted on an arm pivoted near the seabed. The arm oscillates like an inverted pendulum in sympathy with the movement of water in the waves, allowing the transmission of power.
Point absorber	A point absorber is a floating structure absorbing energy in all directions through its movements at/near the water surface. The absorber can be designed to resonate to maximise the power available for capture. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors.
Submerged pressure differential	This is a submerged device typically located nearshore and attached to the seabed. The motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential in the device. The alternating pressure can then pump fluid through a system to generate useful energy.
Terminator	A terminator is a near-surface floating structure similar to a point absorber, but absorbing energy in only one direction. The device extends perpendicular to the wave direction, restraining waves as they arrive. Again, resonance may be employed and the power take-off system may take a variety of forms.
Other	This covers those devices with a unique and very different design to the more well-established types of technology or if information on the device's characteristics could not be determined.

An analysis of all these technologies (see Figure 2.6) shows a diverse range of seven main types of technology being pursued (there are a number of other unique concepts which were grouped within the *Other* category). The most common technology is the point absorber type which includes those technologies which use linear generators (21 devices). The OWC is the second most researched concept (12 systems). The remainder of the devices are relatively equally spread across the other groups identified.

Figure 2.6. Analysis of reported ocean wave energy generation technologies currently in development by type



The wide range of wave devices being researched shows that RD&D is far from producing an optimum solution. It demonstrates that the level of understanding gained is not yet sufficiently developed to clearly show which concept is the more cost-effective. This is made more complex by a lack of collaboration, a lack of shared intellectual property and the absence of development testing standards. The wave devices could be categorised further according to location and depth in which the devices are designed to operate (i.e. offshore, nearshore, or shoreline).

2.4.2 Tidal current

Twenty-five tidal current developments were identified in the previous section. These concepts were categorised firstly according to technology type (see Table 2.2) and then according to the type of fixing method utilised to secure the device in position (see Table 2.3).

Table 2.2. Categorisation of tidal current energy generation technologies into technology type.

Technology type	Description
Horizontal axis turbine	A horizontal axis tidal current rotary device extracts energy from moving water in much the same way as wind turbines extract energy from moving air. Devices can be housed within ducts to create secondary flow effects by concentrating the flow and producing a pressure difference.
Vertical axis turbine	A vertical axis tidal current rotary device extracts energy from moving water in a similar way to wind turbines extracting energy from moving air.
Venturi	This is a Venturi or funnel-like collecting device submerged in the tidal current. The flow of water can drive a turbine directly or the induced pressure differential in the system can drive an air-turbine.
Oscillating hydrofoil	This is a hydrofoil attached to an oscillating arm. The oscillation motion is caused by the tidal current flowing either side of a wing, which results in lift. This motion can then drive fluid in a hydraulic system to be converted into useful energy.

The tidal devices analysed in this report are summarised in Figure 2.7, and are mostly of a rotary turbine nature (20 devices). The horizontal-axis turbine is the most common concept, representing 14 concepts being researched. Six devices are of vertical-axis rotor configuration. Two technologies use the Venturi 'choke' concept to capture tidal current energy, whilst only one system uses oscillating hydrofoils.

Figure 2.7. Analysis of reported tidal current energy generation technologies by technology type

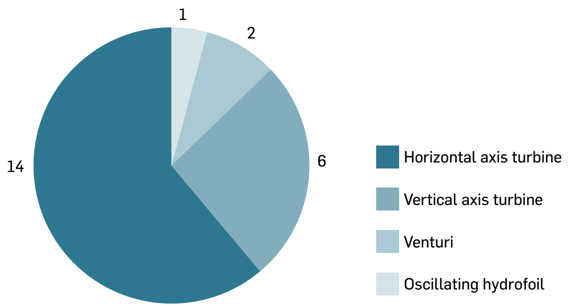


Table 2.3. Categorisation of tidal current energy generation technologies by the method utilised to fix a device into position

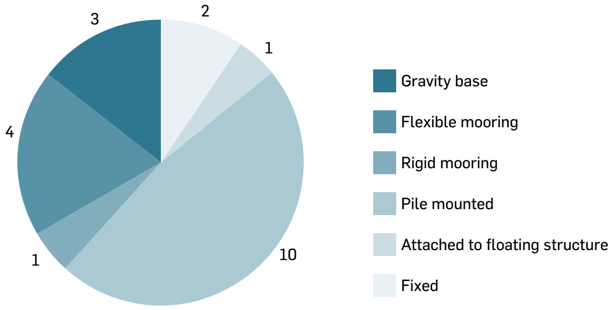
Fixing method	Description
Gravity base	A tidal device that is mounted on a fixed structure, the lower end of which is fixed to the seabed by virtue of its massive weight.
Flexible mooring	The tidal device is tethered via a cable/chain assembly to the seabed, allowing considerable freedom of movement. This allows a device to swing as the tidal current direction changes with the tide, enabling the turbine to maintain an optimum angle to the current direction.
Rigid mooring	The device is secured into position using a fixed mooring system, allowing minimal leeway.
Pile mounted	This principle is analogous to that used to mount most large wind turbines, whereby the device is attached to a pole penetrating the ocean floor. Horizontal-axis devices will often be able to yaw about this structure.
Hydrofoil inducing downforce	The device uses a number of hydrofoils mounted on a frame in such a way as to induce a downforce from the tidal current flow. Provided that the ratio of surface areas is such that the downforce generated exceeds the overturning moment, then the device will remain in position.
Attached to floating structure	A configuration where the turbine is attached to a structure which itself floats, allowing, for example, several turbines to be mounted to a single floating platform which can move in relation to changes in sea level caused by rising/falling tides.
Fixed	The device is secured into a fixed position to the seabed using other techniques.

Figure 2.8 shows that the largest proportion of devices use monopile structures drilled into the seabed to fix the device in position (10 devices), four systems use flexible moorings directly, three use gravity base systems and two are fixed onto the sea floor using other techniques.

Based on this analysis, there are fewer types of tidal device compared to wave. As 20 devices are either horizontal-axis or vertical-axis turbines and as the majority of devices utilise pile mounted fixings, tidal current RD&D seems to be closer to converging on an optimum solution. Developers' design hypotheses have clearly been influenced by and benefited from previous wind turbine R&D. Fourteen technologies are horizontal-axis turbines which suggests that the majority of developers believe this design will deliver the most cost-effective solution to extract energy from tidal currents.

However, a large proportion of concepts researched are vertical-axis. Several different types of drive systems (eg variable speed, fixed speed or direct drive) and fixing methods (eg flexible moorings, pile mounted, gravity base) are still being tested. As in the case of wave energy, the limited amount of demonstration at sea of both types of design so far means that it is uncertain which concepts will prove more cost-effective, reliable and most efficient operating at full-scale.

Figure 2.8. Analysis of reported tidal current energy generation technologies by technology type.



2.4.3 Technology components

The general trend in ocean energy RD&D has seen device developers typically incorporate established *off-the-shelf* technology components. This helps to reduce RD&D costs and reduce risk by using mass-produced, well-tested sub-components. Designing dedicated systems specifically for the manufacture and assembly of ocean energy devices should allow designers to improve and enhance the performance and efficiency of their device. Thus, certain companies are producing dedicated components for more well-developed ocean energy technology. For example, Artemis Intelligent Power Ltd is currently developing an advanced power take-off system for the Pelamis wave energy converter[19]. This is an example of technology acceleration made possible by Government RD&D funding. In this case, the Carbon Trust funded the development through its *Applied Research Grant* scheme (described in section 3.2.3.8).

3 POLICIES

This section reviews the types of policy which support and influence the development of ocean energy technology. Common policies that support many of the technologies analysed in section 2 are assessed, including their impact on government renewable and ocean energy RD&D budgets. Market deployment support mechanisms which aid market deployments are explored and the key policies in individual countries are identified and described. Other important consenting and environmental activities are also described.

3.1 Policy types

IEA member countries are faced with the challenge of achieving energy security, environmental protection and economic efficiency. Ocean energy technologies are largely at the prototype testing phase and have not yet penetrated global energy markets. Ocean energy could contribute to these objectives in the medium to long term, provided policies which offer further RD&D funding and establish support mechanisms to stimulate market deployment are implemented by IEA governments. The IEA categorises[20] policies into three groups that affect technology development and market uptake:

> **Research and innovation policies** that help to develop emerging and improved technologies (eg government RD&D programmes).
> **Market deployment policies** that underwrite the cost of introducing technologies into the market to improve technical performance and to encourage development of an industry (eg market deployment support mechanisms).
> **Market-based energy policies** that provide a competitive market framework, and may internalise externalities in terms of energy security, environmental protection and economic efficiency.

Integrated together, these policies constitute the energy policy context that governments need to establish with respect to renewables[21].

3.2 Research and innovation policies

Research and innovation policies promote technology innovation through the funding of applied research, development and demonstration of technology. In the case of ocean energy, public funding is crucial to advance RD&D and reduce the risk associated with the technology, and to motivate increased private sector involvement. Several government RD&D programmes and government-funded organisations provide support for different types of renewable and ocean energy technology.

Government budgets provided for renewable and ocean energy RD&D from 1974 to 2004 reported to the IEA are described in the following sections to illustrate trends in public funding.

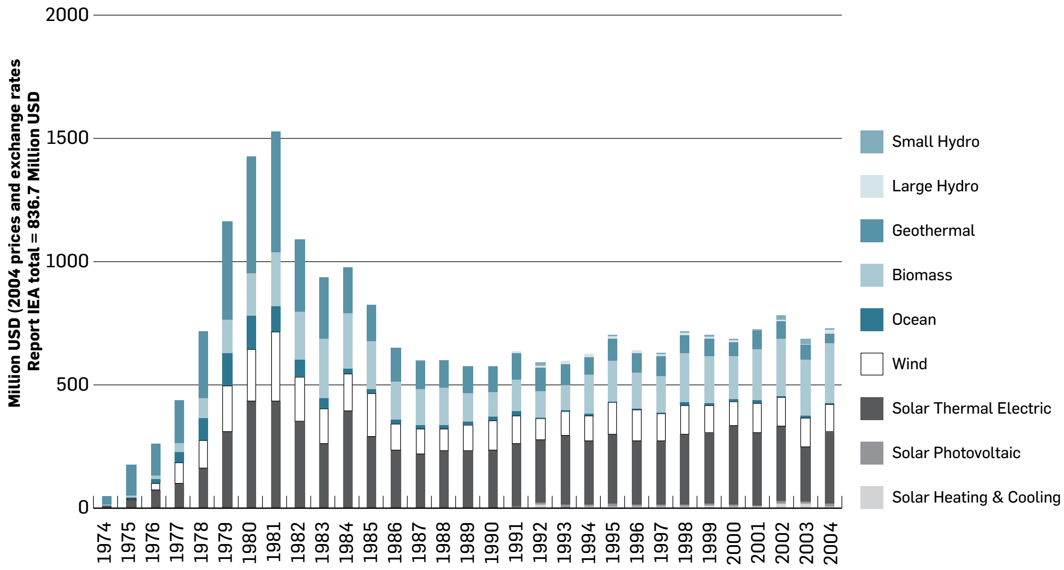
[20] Source: *Renewable Energy, Market and Policy Trends in IEA Countries*, IEA, 2004. http://www.iea.org

[21] The latest update on IEA government renewable energy budgets and policies and measures is presented in *Renewable Energy: RD&D Priorities, Insights from IEA Technology Programmes*, IEA, 2006.

3.2.1 Government renewable RD&D budgets

Total government energy RD&D budgets increased sharply after the oil price rises in the 1970s. Budgets declined to around half of their peak levels by 1987 and remained relatively constant up until 2002. Renewable energy technologies accounted for just 7.7% of total government energy RD&D budgets from 1987 to 2002.

Figure 3.1. Total reported government renewable RD&D budgets in IEA member states 1974-2004



Renewable energy RD&D budgets totalled about USD 23.55 billion from 1974 to 2002. In comparison to other renewables, ocean energy has received only 0.3% of total funding over the same period (see Figure 3.1). This level of funding reflects the lack of confidence shared by many governments in a high-risk technology which has so far not produced large-scale generation (excluding tidal barrage technology). This view is supported by the limited progress in overcoming the challenges faced by ocean energy systems, namely, proving the cost-effectiveness and reliability of devices operating in the harsh marine environment, despite over 30 years of global RD&D. Ocean energy has also had to compete against other technologies, primarily wind, solar and biomass, which do not operate in as severe environments. The available global resource is also less in comparison, and this is reflected by the larger budgets offered to these technologies. On the other hand, advocates of ocean energy express the view that progress so far is a result of limited government budgets and further increased public funding is essential for ocean energy technologies to prove their cost-effectiveness, competitiveness and reliability, to reduce risk significantly (to attract private investment), increase technical improvements and initiate market deployment.

3.2.2 Government ocean energy RD&D budgets

IEA member governments allocated about USD 0.8 billion (2004 prices and exchange rates) for RD&D on ocean energy from 1974 to 2004 (see Figure 3.2). The United States (US) accounted for about 53% of reported governmental RD&D funding. Significant expenditure by the United Kingdom (UK), Japan, Canada and Norway equalled about 41% of ocean technology RD&D budgets in IEA member countries over the same period.

Figure 3.2. Reported government ocean energy RD&D budgets in IEA member states 1974-2004

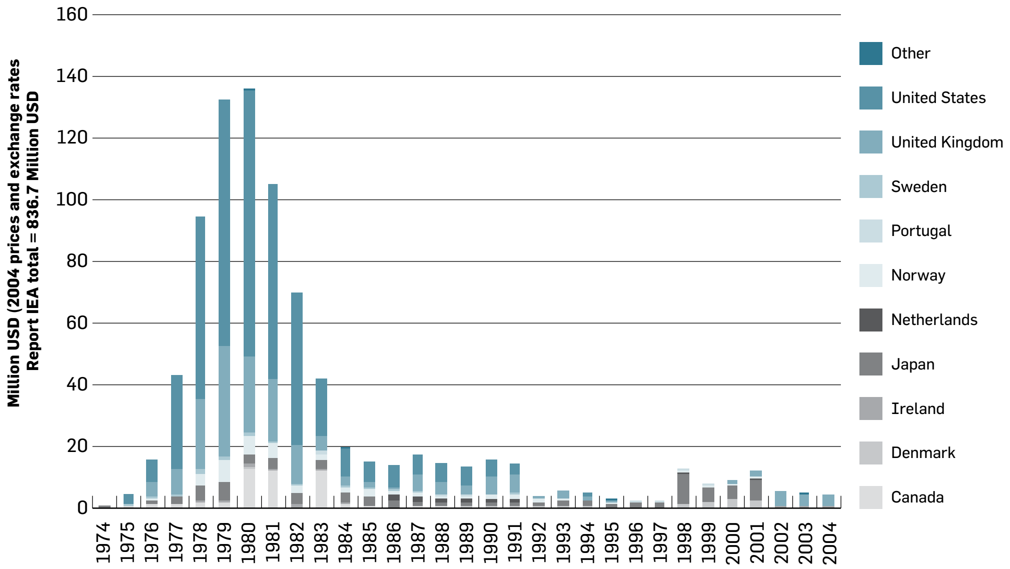


Figure 3.2 shows the increase in government expenditure on ocean energy in the aftermath of the oil price rises in the 1970s. In particular, the US, the UK, Japan, Norway and Canada were prevalent in the period from 1974 to 1984. RD&D peaked in 1980 and rapidly decreased by the mid-1980s owing mainly to the US withdrawing public support for OTEC RD&D. After an initial boom of government RD&D support from 1974 to 1984, the UK became the largest contributor between 1986 and 1991. Global funding was at its lowest from 1992 to 1997, before Japan began to invest heavily between 1998 and 2001 (resulting in the demonstration of the Mighty Whale OWC prototype). Notably, Denmark and Portugal also increased public spending between 1996 and 2001 (resulting in the demonstration of several ocean wave devices). Since 2001, renewed interest in ocean wave and tidal current RD&D in the UK has resulted in increased public spending. Consequently, several full-scale (or near full-scale) prototypes are nearing demonstration at sea.

The following sections describe the various types of energy technology research and innovation policies which support ocean energy. Table 3.1 summarises these policies, identifying the type of technology funded, the total amount made available (and, where possible, the total amount awarded to ocean energy projects) together with the policy timeline[22]. The increasing trend in the number of projects and the recent launch of dedicated RD&D schemes indicate that government expenditure will increase provided RD&D objectives are met.

[22] The government budgets obtained from the IEA for RD&D presented above provide data up to 2004 (this was the only comprehensive dataset available). During the more detailed review of current policies, more recent funding information has been identified for certain countries. Where available, the number of ocean energy projects supported and the amount of funding made available are stated in Table 3.1.

3.2.3 National RD&D policies and funding

There are currently several different types of nationally funded programmes, schemes and organisations that provide financial support to fund the range of activities undertaken during different phases of ocean energy RD&D (see Figure 3.3). The various sources are described below:

> Central government.
> Regional and local government.
> Regional development government agencies.
> Commercial organisations.
> Other government-funded organisations.

Central government technology RD&D programmes are usually coordinated by the department responsible for technology R&D. The amounts awarded can vary and depend on the individual requirements of each project. Competitions are run with deadlines allowing developers to apply for funding, whereby successful applicants must meet certain criteria. Technology programmes are normally open to a range of different technologies including innovative, energy, renewable or low carbon energy technologies. The types of energy technology that are awarded will depend on the priorities of the wider energy context of the particular country. Acceptance criteria and terms and conditions may differ.

Regional and local government can also play an important role in funding ocean energy RD&D projects. This is particularly evident in the US (state funds versus federal funds) and in the UK (Scotland's devolved administration funds versus central Government funds).

Several government-funded organisations focus on environmental protection issues such as mitigating climate change by reducing greenhouse gas emissions or promoting sustainable development. Certain organisations fund the development of sustainable, innovative and new renewable technologies, providing another source of funding for ocean energy within government RD&D programmes.

In the UK, regional organisations, funded by central Government, which are focused on developing regional areas, promoting business enterprise and innovation and generating employment, have also funded ocean energy projects.

Figure 3.3. Research and innovation policies supporting ocean energy RD&D

Country	Name	Techonologies supported (all unless specified)	Total Funding available	Funding for Ocean energy/ No of projects supported
Canada	Climate Change Action Fund Technology Early Action Measures			CAD 0.25 million allocated
Canada	Sustainable Development Technology Canada			1 demonstration project
Denmark	Danish Wave energy Programme	Ocean Wave		EUR 5.3 million
France	Research, Development and Innovation Programme			1 R&D project supported
Ireland	Ocean energy Strategy			
Ireland	Renewable Energy Research, Development & demostration	Ocean Energy	EUR 16,25 million	EUR 26.6 million
Norway	RENERGI (Research Council of Norway)		US 20 million	5 R&D projects supported
Norway	Enova SF – The Energy Fund		EUR 680 million	1 demostration project
Portugal	Agência de inovação SA PRIME – DEMTEC programme		EUR 5 million per year	2 demostration projects
United Kingdom	NRE/Technology Programme		Approx. GBP 18 million per year	GBP 26 million (2000-2005)
United Kingdom	Wavw and Tidal Stream energy Demonstration Scheme	Wave and Tidal Current		GBP 50 million
United Kingdom	Carbon Trust: Applied Research Grants			GBP 2.5 million
United Kingdom	Carbon Trust: Marine Energy Challenge	Wave and Tidal Current		GBP 3.0 million
European Union	Research and Technology Development (RTD) Sixth Framework Programme			EUR 7.2 million
European Union	RTD Seventh Framework Programme		EUR 2,931 million	

– – – *Indicates policy does not have definite end date.*

Examples of national research and innovation policies and funds which support ocean energy projects are detailed in the following sections[23].

3.2.3.1 Canada

The two main central Canadian Government technology RD&D programmes are the Program of Energy Research and Development (PERD) started in 1974 and the Technology and Innovation Research and Development (T&I R&D) Initiative established in 2003 to advance promising greenhouse gas (GHG) technologies. Both are managed and funded by the Office of Energy Research and Development (OERD)[24]. The T&I R&D budget is CAD 115 million over five years. The Decentralized Energy Production research programme (funded out of the T&I R&D Initiative) supports R&D activities to enable the adoption of decentralised energy production systems by 2025. Activities focus on several areas including wave technologies. The Renewable Energy Technologies Program (RETP), which is also funded by the OERD, supports the continued improvement of the economics and efficiency of renewable energy technologies; however, ocean energy projects are not currently funded.

Under its climate change initiatives, the Canadian Government announced several programmes in support of renewable energy technology development and demonstration. The main programme for

[23] The funding figures quoted in these sections may not add up with the government RD&D budgets presented in the previous section owing to the different time periods and alternative sources used.

[24] The Office of Energy Research and Development: http://www2.nrcan.gc.ca/es/oerd/

R&D is Technology Early Action Measures (TEAM), under the Climate Change Action Fund. The programme funds technology projects that promise to reduce GHG emissions, nationally or internationally, while sustaining economic and social development. The programme aims to help accelerate the demonstration and commercial deployment of new technologies. Currently, two ocean energy projects have been granted approximately CAD 250,000 in total for technical assessment and early research activities.

Sustainable Development Technology Canada is a foundation developed through a national government initiative to support the rapid development, demonstration and commercialisation of technological solutions which address climate change and air quality. The 'Pearson College-EnCana-Clean Current Tidal Power Demonstration Project at Race Rocks' is the only ocean energy project currently funded[25].

3.2.3.2 Denmark

The central RD&D programme in Denmark is the Energy Research Programme (ERP), which began in 1974 and is managed by the Danish Energy Authority (DEA). The programme supports the RD&D of energy projects with strategic and practical perspective over a two to three-year period. Financial support of between 50% and 100% of eligible cost is available.

The DEA launched the Danish Wave Energy Programme in 1997 which had an original budget of EUR 5.3 million and operated until 2004 . The programme funded research into 40 wave energy concepts, nine of which advanced to detailed designs. These concepts were tested at part-scale in one of two commercial test facilities in Denmark: the Danish Maritime Institute (DMI) and the Danish Hydraulic Institute (DHI) at the University of Aalborg. Certain devices were also tested at the wave energy ocean test site at Nissum Bredning (also funded by the programme). The programme performed economic assessments of the devices and identified those that were most cost competitive.

One of the most advanced developments, the Wave Dragon overtopping system, received funding from the DEA in the form of grants for separate projects throughout RD&D.

The Public Service Obligation (PSO), which is not government funded, has been applied to ocean wave RD&D, providing grants for the development of Wavestar and Wave Dragon ocean wave devices.

In 2003, the DEA, in collaboration with the two main utilities (funded by the PSO), elaborated RD&D strategies for certain renewables. A national strategy for ocean energy was planned, however, no specific policies or measures to support wave technology have been introduced other than the existing support available to all emerging renewable technologies.

3.2.3.3 France

Two ocean energy projects have been identified in France. Renewable energy research focuses on solar energy, wind, biomass, hydrogen and fuel cells, and geothermal. The Agency for Environmental and Energy Management (ADEME) has provided some funding through the Research, Development and Innovation programme for the development of the SEAREV wave energy device.

[25] Sustainable Development Technology Canada: http://www.sdtc.ca

The French utility EDF has funded its own tidal current energy research programme, Hydroliennes en mer[27]. This project is assessing the feasibility of a tidal current demonstration project at experimental sites in French coastal waters. Hydrodynamic research of France's tidal current resource is underway, using numerical models for current prediction applied to define suitable locations, to assess potential test sites at Brittany and Cotentin. The project is also researching wake effect and wave effect on the performance of tidal turbine current farms. The aim of the project is to set up the demonstration site by 2008. Preliminary studies into the environmental impact of tidal turbines on the marine environment are being carried out in the two regions. The amount of project funding is not clear.

3.2.3.4 Japan

In 1987, research started on an offshore floating 'Mighty Whale' ocean wave device at the Japan Marine Science and Technology Center (JAMSTEC)[28]. The Mighty Whale part-scale prototype was built and moored at the sea test site, 1.5 km off Nansei Town, at a depth of 40 metres in July 1998. The total generated output from August 1998 to December 2001 was 136.2 MW. The open sea demonstration ended on March 2002 and the device was removed. No further development has been initiated as a result of this project.

In 2003, the Japanese Government provided over USD 40 million to the Institute of Ocean Energy at Saga University (IOES) for OTEC research. The IOES has started to investigate new OTEC systems using ammonia/water mixtures as a working fluid. The Matsue National College of Technology at Saga University and the Ministry of Land Infrastructure and Transport have started a demonstration project of the *Impulse Turbine* wave energy converter in Nigata. Discussion is on-going for increased public support for wider OTEC and wave energy RD&D.

3.2.3.5 Ireland

The Renewable Energy Research Development & Demonstration Programme (Renewable Energy RD&D) was launched in 2002 and is due to be completed in 2006. It is managed by Sustainable Energy Ireland (SEI)[29]. The programme is primarily focused on stimulating the deployment of renewable energy technologies that are close to market, and on assessing the development of technologies that have prospects for the future. Four ocean energy projects were awarded almost EUR 0.3 million in total under the programme.

Collectively, the SEI, the Marine Institute (MI)[30] and Enterprise Ireland have provided EUR 883,000 in public funding for industry-based research and development and EUR 307,000 for institutional-based research of ocean energy technology.

In 2006, the Government launched an ocean energy strategy for Ireland. As Ireland has one of the largest wave energy resources in Europe, the programme aims to provide long-term funding both

[26] Danish Wave Energy: http://www.waveenergy.dk/

[27] Hydroliennes en mer: http://www.edf.fr/259i/Homefr.html

[28] http://www.iea-oceans.org/newsletters/news01.pdf

[29] Sustainable Energy Ireland, formerly the Irish Energy Centre, was set up in 2002 as Ireland's national energy agency to promote and assist the development of sustainable energy. http://www.sei.ie

[30] Ireland's national agency to undertake, co-ordinate and assist in marine R&D, promote economic development, and create employment while protecting the environment. http://www.marine.ie

to develop a national ocean energy industry and to utilise the resource to contribute to domestic supply security. The proposed strategy is a four-phase programme estimated to require EUR 26.6 million in Government funding, as illustrated in the table below.

Table 3.1. The planned budget for Ireland's ocean energy strategy

Phase	Year	Task	Cost (EUR million)
Phase 1	2007	Prototype development	4.9
Phase 2	2008-2010	Pre-commercial devices	6.9 - 10.5
Phase 3	2011-2015	Pre-commercial array	10.1 - 11.15
Phase 4		Market deployment	Support mechanism if required

3.2.3.6 Norway

There is considerable Government support for ocean energy RD&D in Norway from a number of programmes and funds. There are at least seven reported ocean energy devices under development in Norway, including three ocean wave, three tidal current and one salinity gradient concept.

3.2.3.6.1 Research Council of Norway – RENERGI

Clean energy for the future (RENERGI, 2004-2013) is a broad energy RD&D programme administered by the Research Council of Norway[31]. RENERGI encompasses all energy research except petroleum, and includes socio-economic and basic research. The primary research areas are renewables (hydro, bioenergy, wind, photovoltaics, thermal solar and ocean energy), energy usage, energy systems (including distribution and transmission), biofuels and hydrogen. RENERGI has a budget for 2006 of NOK 150 million (USD 20 million).

The project funds for 2005 were allocated as follows: 32% to hydrogen, 9% for energy usage, 12% for socio-economic research, 28% for energy systems and 19% for renewables. The five ocean energy concepts currently being developed in Norway have all been awarded funding from RENERGI.

3.2.3.6.2 Enova SF – the Energy Fund

Another source of funding for renewables RD&D comes from Enova SF – the Energy Fund. Enova SF was established in 2001 and has been operating since January 2002. Enova is owned by the Government of Norway, represented by the Ministry of Petroleum and Energy (MPE). Enova aims to ensure the more cost-effective use of public funding for energy efficiency and new energy technology by creating a more target-oriented organisation. The total budget of EUR 680 million will be allocated over a ten-year period. The funding comes from a levy on the electricity distribution tariffs and from grants from the national budget.

Within the framework of the Energy Fund, Enova provides capital grants for new energy technologies, initial investment for market introduction of new energy technologies and obligations to support renewables (explained in section 3.3). Although primarily focused on increasing wind power production capacity to 3 TWh per year by 2010, ocean energy projects are supported. For example,

[31] http://www.forskningsradet.no/renergi

WAVEenergy AS has secured funding from Enova for full-scale demonstration of the SSG wave energy converter at Kvitsoy.

Commercial interest in these technologies is significant in Norway. Several large Norwegian companies are investing in technologies and committing joint funding for further RD&D. For example, the SEEWEC device is being partially funded by the commercial shipping company Fred Olsen, and the energy utility Statkraft AS is involved in the development of a salinity concept and a tidal current concept.

3.2.3.7 Portugal

The National Strategy for Energy, established in 2001, set a target of 9,680 MW for additional electricity generating capacity from renewable energy systems (RES) by 2010, of which 50 MW referred to wave energy. This matched the target of 39% of electricity consumption from RES in accordance with EU legislation. The designation of a zone of sea for testing ocean energy systems and simplification of the consenting process for projects in this area are underway.

Support for R&D comes from Fundação de Ciência e Tecnologia (FCT), the R&D agency belonging to the Ministry of Science and Higher Education, and also from the Agência de Inovação SA, a Government enterprise within the Ministry of Economy and Innovation which supports technological innovation projects.

In 2006, within the framework of the guidelines of the National Strategy for Energy and the Technological Plan, Agência de Inovação launched PRIME (Incentives Programme for the Modernisation of Economic Activities) which provides financial support for technologies that harness renewable energy sources. The budget of over EUR 30 million is distributed among the following projects:

> *SIME* (EUR 15 million) - Incentive Scheme for Business Modernisation.
> *SIME RDT* (EUR 5 million) - Incentive Scheme for Business Modernisation – Research and Technological Development.
> *SIPIE* (EUR 5 million) - Incentive Scheme for Small Business Initiatives.
> *DEMTEC* (EUR 5 million) - Incentive Scheme for the Implementation of Pilot Projects related to Technologically Innovative Products, Processes and Systems.

The DEMTEC programme[32] provides financial incentives for pilot projects of products, processes and technologically innovative systems. Since 2003, the programme has supported the renovation and testing of the Pico OWC Pilot Plant in the Azores, the AWS full-scale demonstration, the Douro Breakwater OWC and the Pelamis demonstration wave farm project.

3.2.3.8 United Kingdom

Sixteen ocean wave concepts that originated in the United Kingdom are currently at different stages of development. Two subsidiaries of non-UK companies are planning demonstrations of ocean wave devices. Eleven tidal current concepts are also in development. This is the highest number of developments in any country and has been primarily motivated by significant Government RD&D financial support, particularly since 2000.

[32] http://www.adi.pt/DemTec.htm

3.2.3.8.1 Department of Trade and Industry R&D Programmes

Ocean wave R&D has been strongly supported in the UK. The first Department of Energy wave energy R&D programme spent GBP 57 million (in 2005 prices) between 1976 and 1982 but was scaled down owing to results indicating very high generation costs. Since 1999 the UK has experienced a resurgence in ocean energy research and the British Government has committed around GBP 26 million overall since 2000.

The current primary RD&D policy vehicle in the UK is the Technology Programme[33] which is managed by the Department of Trade and Industry (DTI). From 2000 to 2005 the DTI New and Renewable Energy (NRE) R&D Programme, which is now part of the Technology Programme, committed approximately GBP 10 million on eight ocean wave device concepts alone. Of these projects, three have been abandoned because technical and economic evaluation indicated that generation costs would be commercially unviable given foreseeable future market conditions. Although this programme has advanced certain technology considerably based upon the results from these projects, the long term economic prospects for wave energy are still highly uncertain.

In the same period the DTI's NRE R&D Programme also supported work to develop and evaluate a number of tidal current energy device concepts. The Programme has so far committed over GBP 16 million to 21 tidal current projects covering ten different device concepts. More than two thirds of the budget committed to date is on projects that are either on-going or have recently been approved and are just beginning.

3.2.3.8.2 The Carbon Trust

The Carbon Trust (CT) is an independent company, funded by the Government, that aims to help the UK move to a low carbon economy by helping business and the public sector reduce carbon emissions and capture the commercial opportunities of low carbon technologies.

The CT Marine Energy Challenge[34] is a technology acceleration programme that focused on advancing the development of eight wave and tidal current concepts. The programme was completed in summer 2005, having run for 18 months, and provided GBP 3 million for targeted engineering support which was intended to improve the understanding of wave and tidal current generation technologies, including costs and performance. Additional skills and specific experience from a range of engineering consultants were applied to help advance designs. The device developers involved claimed the rate of development has been improved through these types of specialist collaboration.

The CT Applied Research Grants scheme has also provided over GBP 2.5 million for specific ocean energy research projects since the scheme started in 2001[35]. The largest grant was awarded to the European Marine Energy Centre (EMEC) in Orkney, which received a grant for GBP 1,195,000 in 2002 to help fund EMEC's wave energy device test site. The CT also plans to provide further support for the new tidal current test area. The CT has also made a venture capital investment of over GBP 1.5 million in Ocean Power Delivery Ltd.

[33] http://www.dti.gov.uk/technologyprogramme/

[34] The results were published in February 2006. Estimated cost and performance results are not published in detail for commercial reasons. http://www.thecarbontrust.co.uk/carbontrust/about/publications/FutureMarineEnergy.pdf

[35] Source: http://www.thecarbontrust.co.uk/carbontrust/low_carbon_tech/dlct2_1_4.aspx

3.2.3.8.3 Other sources of funding

Wave Dragon AS is currently in discussion with the Welsh European Funding Office[36] over a GBP 5 million grant to fund a demonstration project with the aim of installing several full-scale ocean wave devices off the Welsh coast.

A range of other organisations and sources have also provided smaller contributions in comparison to the DTI programme. These grants tend to be required for earlier R&D projects, such as proof of design concepts, feasibility studies and small-scale simulated testing of prototypes, which must be completed before a developer can apply to a central programme for funding. These organisations include Scottish Enterprise and the npower Renewables Juice Fund[37].

3.2.4 European Union

Since 1995, the European Commission (EC) has allocated over EUR 30 million to ocean energy projects. The Framework Programme (FP) is the European Union's (EU) main instrument for funding research and development. The FP is proposed by the EC and adopted by Council and the European Parliament following a joint decision. FPs have been implemented since 1984 and cover a period of five years, with the last year of one FP and the first year of the following FP overlapping. Total EC funding for ocean energy under FP5, including demonstration projects, was approximately EUR 4.5 million. The current FP is the Sixth Framework Programme which will be running until the end of 2006 and has provided EUR 7.2 million.

3.2.4.1 Ocean energy support under the Sixth Framework Programme (FP6)

Under FP6, ocean energy projects can apply for funding for research via the Sustainable Energy Systems (SES) thematic sub-priority or through the medium to long term Research Objective (DG Research), if the research activity has an impact in the medium to long term. Demonstration projects are funded via SES or through the short to medium-term Research Objective (DG Energy and Transport). The Intelligent Energy Europe Programme provides support for research attempting to overcome non-technical barriers. To qualify for funding, each project must assemble the resources needed to achieve its objectives. Project activities may range up to several million Euros and there is no minimum threshold. Projects typically last for two to three years but there is no limit on duration, if justified to deliver the objectives. A minimum of three participants from three different countries is required[38]. Third Country participants may be included, with a possibility of Community financial support for certain groups of countries.

[36] An executive agency of the National Assembly for Wales to manage all aspects of European Structural Fund Programmes in Wales. http://www.wefo.wales.gov.uk/

[37] http://www.npower.com/At_home/Juice-clean_and_green/About_Juice.html

[38] FP6 was open to Member States and Associated Candidate Countries; Associated Countries; Third Countries including: Russia and Newly Independent States; Mediterranean Countries; and Western Balkan Countries holding Science and Technology cooperation agreements.

Table 3.2. R&D projects currently negotiating new EU funding under FP6

Technology	Characteristics	RD&D activity funded	Funding
Sustainable Economically Efficient Wave Energy Converter (SEEWEC)	Floating rig with several wave energy converter point absorbers attached	Development of a second generation SEEWEC wave energy converter using experience gained from monitoring a 1:3 scale laboratory rig and a first generation 1:1 point absorber prototype. The project will focus on robust cost-effective solutions and design for large-scale (mass) manufacturing.	€2.3 million
Seawave Slot-cone Generator (WAVESSG)	Overtopping wave energy converter	Demonstration of the full-scale device. The main objective of the project is to operate a full-scale prototype in a 19 kW/m wave climate, including turbine, generator and control system.	€1 million
Wave Dragon	Overtopping wave energy converter	Construction of a full-size 4-7 MW prototype. Comprehensive testing to validate the technical and economic feasibility will be performed.	€2.47 million

Ocean energy projects have received approximately EUR 7.2 million in support from FP6. The technologies that were negotiating funding at the time of this study under FP6 are summarised in Table 3.2.

The Coordinated Action on Ocean Energy (CA-OE)[39] is an on-going project and has received EUR 1.5 million from the EC under FP6. CA-OE follows on from the European Wave Energy Thematic Network that was funded under FP5.

3.2.4.2 Ocean energy support under the Seventh Framework Programme (FP7)

In September 2005, the EC approved the proposals for the 7th Framework Programme[40] of the European Community. This proposed several research, development and demonstration programmes, named: Cooperation, Ideas, People and Capacities. Activities to be undertaken by the Joint Research Centre (JRC), as well as research under the Euratom treaty, are also proposed.

FP7 is proposed for the period 2007 to 2013, and will be the successor to the current FP6. FP7 will include the Cooperation – Collaborative Research Programme. This will support a wide range of research activities carried out in trans-national cooperation, from collaborative projects and networks, to the coordination of national research programmes. International cooperation between the EU and Third Countries is an integral part of this action.

The action is industry-driven and organised in four sub-programmes:

> Collaborative research will constitute the bulk and the core of EU research funding.
> Joint technology initiatives will be created mainly on the basis of the work undertaken by the European technology platforms.
> Coordination of non-Community research programmes.
> International co-operation.

[39] For further details go to http://www.wave-energy.net
[40] http://www.cordis.lu/fp7/

Energy is one of nine thematic priorities of the Cooperation – Collaborative Research Programme. A total fund of EUR 2,931 million is available for energy collaborative research. Ocean energy will be eligible for application for funds under the renewable electricity generation category.

Ocean energy technology could also receive support from the Capacities research programme. The objectives of this programme are to:

> Support research facilities, in particular, for the benefit of SMEs.
> Support research potential of European regions (Regions of Knowledge).
> Stimulate the realisation of the full research potential (Convergence Regions) of the enlarged Union and build an effective and democratic European Knowledge society.

The EC believes the following issues need to be addressed by ocean energy funded research for the sector to progress:

> Define medium to long term R&D needs, including research facilities (including human and technical resources), standards and terminology.
> Device efficiency must be improved.
> Capital and operations costs should be validated, including decommissioning costs.
> Environmental and ecological implications.
> Involvement of larger industry to minimise technical and financial risks and provide political support.
> Consortia should include end-users or utilities.
> Assess the environmental and ecological implications.
> Disseminate and apply best practices.
> Dedicated association involving all stakeholders could assist in common issues.
> Networking should be encouraged to promote best practices.

3.2.5 United Nations Industrial Development Organization

The United Nations Industrial Development Organization[41] (UNIDO) has funded Italy's only ocean energy development project – the Kobold vertical-axis tidal turbine that was demonstrated at near full-scale in the Straight of Messina from 2001 until January 2005. The developer of this pilot project, Ponte di Archimede SpA, was awarded UNIDO funding for the demonstration in 2004 and 2005.

The Republic of Indonesia's State Ministry of Science and Technology has stated its interest in pilot testing the Kobold turbine in a selected site in Indonesia. The demonstration project is to be funded by the UNIDO. The Republic of the Philippines Department of Energy has also confirmed its interest in setting up a demonstration project in cooperation with the UNIDO.

3.3 Market deployment policies and support mechanisms

Market deployment policies deliver support mechanisms to underwrite the cost of introducing new and emerging energy technologies into the marketplace. They can provide subsidised income for

[41] UNIDO aims to improve the living conditions of people and promote global prosperity through offering tailor-made solutions for the sustainable industrial development of developing countries and countries with economies in transition. http://www.unido.org

the electricity generated, to bridge the cost gap between the first production models and commercial models. Subsequent improvements in the technical performance (due to the improved understanding of the technology and energy resource from initial deployments) and the reduced capital costs (due to more efficient economies of manufacturing products in larger quantities) can help to reduce overall generation costs and encourage the development of an industry. Market deployment support mechanisms can also reduce the risk associated with initial deployment projects and attract greater private investment.

Several policy instruments outlined below have helped the market deployment of renewable energy systems:

> **Investment incentives** are used to reduce the capital cost of deploying renewable energy technologies and can also reduce investor risk, for example, through the provision of **capital grants**. Other types of incentive include **third-party finance** arrangements where government assumes risk or provides low interest loans.
> **Tax measures (investment and production tax credits)** can encourage production by reducing the tax payments for owners of a project.
> **Incentive tariffs (guaranteed prices/feed-in tariffs)** are set by governments and provide a guaranteed price to a generator for electricity generated from renewable sources for a designated time period. The price of the feed-in tariff provided depends on the renewable source's current generation cost, the renewable targets in a country, the wider energy policy of a country and how much capacity is already installed. Feed-in tariffs typically have capacity limits and decrease as the amount of installed capacity increases. It is important that the feed-in tariff is in balance with the rate of improved generation cost of the subsidised technology, so as not to artificially skew and negatively affect other types of generation.
> **Obligations** force suppliers of electricity to provide a set quantity of electricity (in kWh) from renewable sources, thus effectively guaranteeing a market for renewable technologies. Such policy instruments often use **tradable certificates** that are accumulated as a supplier meets its obligation. These can then be sold on the open market to other suppliers that have not met the obligation quota. The renewable energy **targets** set by a country will determine different levels of obligations, with a penalty for non-compliance.

3.3.1 Renewable energy systems

There is a broad range of market deployment policies worldwide which encourage greater penetration from renewable energy systems. An overview of the support mechanisms available to renewables (typically targeted towards the more well-established technologies including onshore and offshore wind, solar PV, biomass, and geothermal) is given in Figure 3.4[42].

[42] For further details on these policies, readers should view the IEA Global Renewable Energy Policies and Measures Database at http://www.iea.org/textbase/pamsdb/grindex.aspx

Figure 3.4. National policies that support the market deployment of ocean energy systems compared to other renewable support mechanisms

		Australia	Austria	Belgium	Canada	Denmark	France	Germany	Greece	Ireland	Italy	Japan	Korea	Netherlands	New Zealand	Norway	Portugal	Spain	Sweden	United Kingdom	United States	Brazil	China	India	Mexico	South Africa	Finland
OCEAN ENERGY SYSTEMS	Capital Grants																x			x							
	3rd Party Finance																										
	Investment and Production Tax Credits							x													x						
	Obligations																			x						x	
	Tradable Certificates																			x							
	Guaranteed Prices/feedin tariffs							x									x			x							
	Regulatory and Administrative Rules																x			x							
OTHER RENEWABLES	Capital Grants	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x		x				x
	3rd Party Finance			x	x		x	x					x	x				x			x	x					x
	Investment and Production Tax Credits			x	x		x	x		x			x	x			x	x	x		x				x		x
	Obligations	x	x	x	x	x	x	x		x	x	x	x	x	x	x		x		x	x	x	x			x	x
	Tradable Certificates	x		x							x		x	x		x			x	x		x					
	Guaranteed Prices/feedin tariffs		x		x	x	x	x	x	x	x		x	x			x	x	x		x	x	x				
	Regulatory and Administrative Rules	x	x	x		x	x	x	x	x	x		x		x	x	x	x	x				x		x		x

x – *Denotes policy instrument set up in country.*

3.3.2 Ocean energy systems

As shown in section 2, ocean energy technologies are relatively immature compared to other renewable and conventional generation technologies, and are generally at the part-scale or full-scale prototype demonstration stage in overall terms of RD&D status. Market deployment policies that support these technologies are not yet as widespread as other renewable policy instruments, as illustrated in Figure 3.4.

The key policy developments that provide support mechanism for ocean energy systems are described below.

3.3.2.1 Germany – Feed-in tariffs and tax incentives

Germany has very little ocean energy resource in comparison with other European countries. However, ocean energy is included under the existing renewable framework. Ocean energy projects are eligible for the same feed-in tariff of EUR 0.0767/kWh available to hydropower installations.

The previous tax incentives scheme, which offered investors 100% tax-free investments in renewable energy projects, has been changed by the new German Government. There is no more special regulation for renewables. However, a linear tax depreciation still applies as for any other 'tangible fixed assets'. The success of the previous scheme is illustrated by the size of the wind industry. According to figures in December 2005, there are approximately 18.5 GW of wind turbines installed onshore and offshore. Licenses have been granted for 11 new offshore wind farms in the North Sea and Baltic Sea.

3.3.2.2 Portugal – Capital grants and feed-in tariffs

Portugal launched the highest feed-in tariff to support wave energy projects of all IEA member countries, initially offering EUR 0.23/kWh for electricity generated from the first 20 MW of installed wave energy devices (for a maximum of 15 years) as a result of law DL 339-C/2001 introduced in 2003. However, this law was replaced by DL 33-A/2005in February 2005 which abolished the explicit tariff for wave energy. Feed-in tariffs for 'innovative technologies' must now be agreed on a case-by-case basis between the developer and the Government. These negotiations may take into account commercial issues such as the ownership of the technology and where the machines are to be manufactured, as well as the cost of generation, system performance and current installed capacity. A revision of the fixed tariff structure for the first 20 MW of wave energy systems was being discussed at the time of this study[43].

The Aguçadoura wave farm project, led by the Enersis Group and OPD and scheduled for installation off the Portuguese coast in 2006, will be supported by a feed-in tariff of EUR 0.23/kWh (which Enersis has negotiated for the three devices to be installed in the first phase of the project). According to OPD, the tariff will apply to the first three devices and a further 28 devices (which will be installed subject to satisfactory performance of the first phase)[44]. This development demonstrates the impact of a market deployment policy and support mechanism as it will be the first full-scale wave farm deployed. It also indicates how far these technologies are from true commercial competitiveness. The DEMTEC programme (run by Agência de Inovação and described in section 3.2.3.7) has provided a EUR 1.25 million grant to help fund the Pelamis demonstration project.

3.3.2.3 United Kingdom – Obligations

The Renewables Obligation is the British Government's main policy instrument for supporting renewable energy[45]. The mechanism requires licensed electricity suppliers to source a specific and annually increasing percentage of the electricity they supply from renewable sources, effectively guaranteeing a market for the renewables which are less cost competitive compared to conventional generation.

The Obligation is enforced by an Order (Statutory Instrument) made under the terms of the Utilities Act 2000, introduced in April 2002. The Obligation requires suppliers to source an annually increasing percentage of their sales from renewables. For each MWh of renewable energy generated, a tradable certificate called a *Renewables Obligation Certificate* (ROC) is issued. Suppliers can meet their obligation by either acquiring ROCs or paying a buy-out price of GBP 30/MWh, or a combination of the two. When a supplier chooses to pay the buy-out price, the money it pays is put into the buy-out fund. At the end of the 12-month Obligation period, the buy-out fund is recycled to ROC holders.

The current target is 5.5% for 2005/06, rising to 15.4% by 2015/16. It is expected that the Obligation will help to provide support to industry of GBP 1 billion per year by 2010. Ocean wave and tidal current technologies are eligible under the scheme.

[43] Source: Frank Neumann, February 2006.

[44] Source: Ocean Power Delivery, December 2005.

[45] http://www.dti.gov.uk/renewables/renew_2.2.htm

The Renewables Obligation (Scotland), or ROS, is the Scottish Executive's (Scotland's devolved administration) main policy instrument to support renewable sources of energy. The ROS creates an incentive for the development of new renewable electricity generating capacity by requiring licensed suppliers to supply increasing proportions of renewables electricity. The ROS was introduced, following full consultation, on 1 April 2002 in parallel with the identical Renewables Obligation covering England and Wales (explained above).

In 2005, the Executive commenced a review of the Renewables Obligation (Scotland). The consultation document published proposed potential changes exclusive to Scotland. The first of these was that the ROS might be amended to provide additional support to emerging technologies, notably wave and tidal energy. After consideration of the response, the Executive believes that there would be merit in altering the ROS to provide increased support in the form of additional ROCs (or multiple ROCs) for output from wave and tidal energy systems only. Once the amount and duration of any support that might be awarded are established, limiting any potential impacts on investor confidence, the subsequent changes would take effect from April 2007.

3.3.2.4 United Kingdom – Capital grants and guaranteed prices

In 2006 the DTI launched the *Marine Renewables Deployment Fund*[46] (MRDF). The total amount of funding allocated under this scheme is up to GBP 50 million. The scheme will fund the gap between R&D and pre-commercial deployment on wave and tidal current technology in UK marine areas. The aim is to encourage the development of a sustainable UK wave and tidal current industry, and to maximise the successful development of cost-effective marine technologies in the long term. This will be achieved by enabling the early stage pre-commercial operation and sea trials of a number of wave and tidal current energy technologies.

The scheme's detailed objectives are listed below:

> To construct and install a number of early grid-connected wave and tidal stream power devices.
> To operate these devices for an extended period.
> To capture key data on the resource, costs (construction, installation, commissioning, operational and maintenance) and energy performance and revenue.
> To produce in a clear, transparent and unambiguous report, an economic evaluation of all projects supported by the scheme, while maintaining the confidentiality of commercially sensitive information.
> To undertake rigorous and thorough evaluations of the environmental advantages and disadvantages of the devices supported.
> To stimulate the UK supply chain.

The MRDF will provide GBP 42 million to fund the *Wave and Tidal Stream Energy Demonstration Scheme*[47]. The scheme will support the deployment of multiple, full-scale wave or tidal stream electricity generating devices connected to the UK grid. It will do this through a combination of capital grants (25% of eligible costs) and revenue support (GBP 0.1/kWh in place for a maximum of seven years from commissioning). In addition to this, projects are entitled to receive the market

[46] http://www.dti.gov.uk/renewables/renew_marinerenewdf.htm
[47] http://www.dti.gov.uk/renewables/business_pdfs/dtiwaveandtidalscheme2006.pdf

value of the electricity and *Renewables Obligation Certificates* that they generate. (Wave and tidal stream single devices remain eligible to apply for funding under the UK technology RD&D programme described in section 2.)

To ensure that the benefits of the scheme are available to a number of different technologies, the total funding received by any project under the scheme will be subject to a cap of GBP 9 million. The costs of grid connection are eligible for inclusion in project costs. The MRDF will also set aside some funding for the 'infrastructure' required for the scheme and targeted research to better understand the resource.

The application process has been designed in coordination with the Crown Estate[48] which owns and leases the seabed 12 km from shore around the whole of the UK. The Crown Estate will provide temporary leases for those developers wishing to complete exploratory investigations to assess the feasibility of sites.

3.3.2.5 United States – Tax credits

The Energy Policy Act of 2005 (Public Law 109-58) is a statute which was passed by the United States Congress on 29 July 2005 and signed into law on 8 August 2005. The Act provides tax incentives and loan guarantees for energy production of various types[49].

The Act recognises ocean energy sources for the first time as separately identified renewable technologies. The 10-year Production Tax Credit (PTC), which provides incentives to investors, has been extended to resources not previously covered, including wave, tidal current, and ocean thermal energy.

The US federal production tax credit has greatly aided the domestic wind industry but has not been sufficient to spur the development of 'closed-loop' biomass systems, which also qualify for the credit. The potential benefit or impact on ocean energy of this measure is unclear and may not benefit projects in the short term due to high investment risks.

The Energy Policy Act also makes ocean energy eligible for funds authorised for 'appropriation' for development of renewable energy projects. Prior to the Energy Policy Act, no other federal legislation since the Ocean Thermal Energy Conversion (OTEC) Act of 1970 had accorded recognition or 'authorised' funding for ocean energy.

3.4 Other policies impacting on ocean energy developments

Regulatory and administrative policies and frameworks, such as consenting, environmental impact and planning procedures, can simplify the process of deploying technology by clearly instructing developers how to secure consent for a project from the relevant authority or government department. These policies can also address likely barriers, which may prevent the growth of the industry to help meet energy targets while ensuring environmental impacts are minimised. For example, policies can permit the demonstration of devices at sea in the European Union without the requirement of a Strategic Environmental Assessment.

[48] http://www.thecrownestate.co.uk

[49] http://www.eere.energy.gov/femp/about/legislation_epact_05.cfm

An example of consenting procedures published by the British Government aims to clarify the process of gaining consent for the demonstration of multiple pre-commercial full-scale wave or tidal current systems. Without a clear process, developments can be delayed.

3.4.1 United Kingdom – consenting procedures for multiple device demonstration

In parallel with the Wave and Tidal Stream Energy Demonstration Scheme, the DTI published *Guidance on consenting arrangements in England and Wales for a Pre-commercial demonstration phase for wave and tidal stream energy devices (marine renewables)*[50]. This sets out the application for existing lease and consenting procedures for all small-scale marine renewable energy generation demonstration devices in English and Welsh territorial waters[51].

In terms of environmental regulation, all demonstration projects will be subject to the requirements of the Environmental Impact Assessment (EIA) regulations and the Habitats Regulations (where applicable) in the normal way, and will be required to produce an adequate EIA to accompany any consent application. Larger commercial-scale wave and tidal stream projects will only go ahead on the basis of a full Strategic Environmental Assessment (SEA) and a Crown Estate site lease competitive round. This is not expected to happen for several years owing to the present development status of the technology. It is planned that the monitoring and research work undertaken during the demonstration phase will significantly contribute to and form part of the SEA.

3.4.2 United States – consenting exemptions for demonstrations[52]

Potential barriers preventing the demonstration of technologies at sea in the US were overcome using temporary exemptions. Device developers had applied for licences to operate from the Federal Energy Regulatory Commission (FERC). However, the application process required technology data that could only be gathered from demonstration, representing a regulatory barrier to development. FERC agreed to provide limited waivers from licensing to developers of demonstration projects to allow them to experiment, provided they do not generate electricity commercially.

For example, in April 2005, Verdant Power, developer of the tidal turbine project in the East River, New York, requested consent for the demonstration of six turbine units and to supply power to the grid to test the technology's capabilities. In the absence of an exemption, the developer would have had to wait an additional year before it could complete all the studies necessary to receive a licence. As a result, FERC made a narrow exception to its otherwise mandatory licence requirement. FERC decided that developers could obtain a limited exemption from licensing (Verdant was given 18 months) as long as they did not generate power for commercial purposes.

The Materials Management Service (MMS) has recently been assigned jurisdiction over ocean energy resource use, and is currently in the rulemaking process, attempting to define the regulations and process for ocean energy permitting[53].

[50] http://www.dti.gov.uk/renewables/publications/pdfs/guidanceonconsentingarrangements.pdf

[51] The Scottish Executive (which has responsibility for consents and planning processes in Scotland) is expected to apply the same framework for demonstration projects.

[52] Source: Carolyn Elefant, Ocean Renewable Energy Coalition, 2005.

[53] Source: US Department of Energy, 2006.

4 SUPPORT

This report identifies a wide range of companies, institutions and organisations which support ocean energy RD&D and are actively helping the industry to develop. These can be grouped into one of four types outlined below:

1. **R&D support services and facilities** provide practical support in the form of design facilities, and laboratories for simulated testing of models and prototypes.
2. **Ocean testing facilities** provide grid-connected sites to enable demonstration at sea.
3. Professional services provide expert and specialist consultancy based upon experience in areas such as hydrodynamics, composites, engineering, power electronics and marine structures.
4. **Other supporting organisations** may perform a range of non-technical support (ie not directly involving the development of a technology).

This section describes the support and uses examples identified during the analysis of the technologies in development to illustrate types one, two and four listed above. Professional services are typically offered in conjunction with research and testing facilities, other supporting agencies, or from commercial organisations.

4.1 R&D support services and facilities

National institutes, universities and private laboratories provide practical services and facilities such as design and computer modelling facilities, information repositories, and facilities to simulate ocean energy conditions for part-scale modelling testing. These are typically available to a range of new and emerging technologies.

National institutes tend to provide facilities to support non-technical and early stages of technology R&D. For example, the Korea Ocean Research and Development Institute (KORDI) is an example of a Korean national R&D institute that has been engaged in various R&D activities of ocean science and technology, contributing development of ocean-related national policies and advancing ocean development. KORDI has undertaken initial R&D work on two ocean energy projects in recent years.

Portugal has a number of important government-funded research institutes that have contributed greatly to the understanding of the ocean wave resource and the development of OWC technology. For example, the Instituto Nacional de Engenharia Tecnologia e Inovação[54] (INETI) has carried out research on wave energy since 1983. It focuses on resource assessment, device modelling, control systems, monitoring of device performance and grid integration.

Commercial laboratories also provide support. For example, Powertech Laboratories Inc[55], based in Greater Vancouver, Canada, has several electrical utility innovation and technology laboratories, and has world-renowned expertise and testing facilities for power quality, power system stability, grid integration, materials performance, storage technologies, and monitoring the environmental

[54] http://www.ineti.pt/

[55] http://www.powertech.bc.ca/cfm/index.cfm

performance of new and renewable energy systems. Powertech is involved in a tidal current demonstration project in Canada.

Universities throughout the world have been involved in ocean energy research for several years. For example, the Instituto Superior Técnico[56] (Portugal) has carried out research on wave energy since 1978. It provides research facilities to support mathematical modelling, development of control systems, and testing of mechanical (air turbine) and electrical generator equipment for wave energy power plants (in particular, for OWC and point absorber technology).

University departments may be actively involved in the development of a technology or part of that technology. For example, Ghent University's Department of Engineering is a member of the SEEWEC project developing point absorber wave energy technology. The university is coordinating the project and performs the hydrodynamic analysis and composite R&D. Several other universities are developing ocean energy technologies. (Several device developers have also spun out of university research programmes.)

Certain universities work in collaborations, pooling resources to tackle challenging areas of research. These projects are often funded from government research funds. For example, the SUPERGEN Marine initiative[57] consists of academics from several universities and is currently embarking on an ambitious work programme to fill some of the critical gaps in the knowledge of the fundamental science of wave and tidal current energy. There are also numerous universities and research institutes throughout the world with wave tanks, tow tanks, wind tunnels, and flume systems (of varying complexities) which can support the earlier stage of RD&D.

4.2 Ocean testing facilities

Of particular importance to ocean energy RD&D has been the development of specialised testing facilities for ocean energy technology which provide test sites and infrastructure to aid sea trials of grid-connected, full-scale prototypes. The demonstration of prototypes at sea is an essential step in the RD&D process to increase understanding of costs, improve performance, and prove reliability and survivability. However, the cost and risks associated with grid connection from offshore has presented an economic barrier to developers wishing to deploy single devices.

To overcome this barrier, the European Marine Energy Centre (EMEC)[58], launched in 2003 and established at Orkney in Scotland, aims to accelerate development by leasing temporary offshore test beds for wave and tidal developers, providing grid infrastructure (11 kV distribution network) and equipment to measure ocean energy input and output. EMEC is a commercial enterprise and received substantial public funding to construct the wave and tidal test sites. This also means that developers need not apply for consents or permission, or undergo a separate environmental impact assessment. The proposed Wave Hub concept plans to help initial pre-commercial deployment of wave farms by constructing an offshore grid connection point for several wave farms.

[56] http://www.ist.utl.pt/

[57] The Marine Energy Research Consortium (United Kingdom) commenced in October 2003 following the award of GBP 2.6 million under the Engineering and Physical Sciences Research Council's (EPSRC) SUPERGEN Programme. http://www.supergen-marine.org.uk/index.html

[58] EMEC has received funding from the British Government, the Carbon Trust and the Highlands and Islands Enterprise among others. http://www.emec.org.uk/general.html

The Irish Government has also funded an ocean testing facility in Galway Bay which designates an area of sea to test large-scale (approximately $^{1}/_{4}$ of full-scale) wave devices. Wave measuring equipment has been installed and the first device was installed in 2006 (grid connection is not included). This has been incorporated into Ireland's ocean energy strategy, to provide the testing facilities for selected technologies.

4.3 Other supporting organisations

Several other types of organisation support the ocean energy sector.

A number of national working groups have been funded and are coordinated by governments. For example, the Federal Ocean Energy Working Group (FOEWG) was established in Canada in 2005. FOEWG consists of approximately 40 members including eight Government departments and agencies. The FOEWG's Ocean Energy Atlas Project is in progress and aims to comprehensively assess and map the Canadian tidal current and wave energy resource.

Industry associations are representing developers to win more political or financial support and help markets develop. For example, the Ocean Renewable Energy Coalition (OREC) is a trade association that promotes and advances the commercial application of ocean energy. OREC played an important part in ensuring ocean energy was included in the renewables inventory in the US Energy Act of 2005. Established in 2005, the European Ocean Energy Association[59] aims to attract private investment into the ocean energy industry and encourage the commercialisation of ocean energy prototype technologies. The association will focus on the consent procedures and development of industry standards.

Not-for-profit organisations include the Wave Energy Centre – Centro de Energia das Ondas[60] – in Portugal which was set up in 2003. The centre is dedicated to the development and promotion of wave energy through technical and strategic support to companies, R&D institutions and public organisations. The centre undertakes R&D projects to support the development of wave energy on both national and international levels, including the Pico OWC Plant and the Wavetrain project.

The International Energy Agency provides useful vehicles to promote communication and collaboration among stakeholders within RD&D. The IEA's Implementing Agreement on Ocean Energy Systems[61] commenced in October 2001 and aims to enhance international collaboration to make ocean energy technologies a significant energy option in the mid-term future. Through the promotion of RD&D and information exchange and dissemination, the Agreement's objective is to lead to the commercialisation of ocean energy technologies. Current priorities are ocean waves and tidal current systems.

The Coordinated Action on Ocean Energy (CA-OE)[62] is an on-going project and has received EUR 1.5 million from the EC under FP6. CA-OE follows on from the European Wave Energy Thematic Network that was funded under FP5. The main objective is to develop a common knowledge base that is required for coherent development of R&D policies in Europe, the dissemination of this knowledge base and promotion of ocean energy technologies.

[59] Further details on the association are included in the IEA OES newsletter, issue 5: http://www.iea-oceans.org/newsletters/news5.pdf

[60] http://www.wave-energy-centre.org/

[61] http://www.iea-oceans.org/

[62] For further details please visit http://www.wave-energy.net

5 BARRIERS

This section gives an overview of the main barriers that are currently restricting the development of ocean energy technologies[63]. For example, poor understanding of the energy conversion performance of a device may restrict the ability to accurately predict energy output and create difficulties in securing financing for projects. Lack of understanding of the environmental impacts may prevent a demonstration project receiving permission from the relevant authorities. Uncertainties surrounding energy production, in terms of power flow, fault levels and voltage issues, could delay arrangements over grid connection. The absence of development, testing and measurement standards complicates the comparison of different systems and makes it difficult for policy-makers, investors or developers to decide which system is most suitable.

5.1 Insufficient demonstration of full-scale prototypes

The immediate barrier that is preventing progress is the lack of sufficient demonstration of prototypes in the marine environment to prove technologies work as predicted. Demonstration at full-scale or near full-scale is essential to establish the actual cost and energy conversion performance of a device and enable predicted cost and performance data to be validated and evaluated. Such testing is also vital to prove the survivability and the reliability of a device as well as to validate scalability (ie the progression from part-scale to full-scale prototypes). Monitoring and measurement of energy input and output during tests are necessary to validate designs and improve comparability of results. Sea trials are key to reducing the high technical risk associated with this technology and to encourage greater private investment in RD&D. Certain market deployment policies are aimed at trying to motivate developers to perform a minimum amount of testing at this scale. For example, the UK Wave and Tidal Stream Energy Demonstration Scheme will fund a device only if it has operated in representative sea conditions at full-scale or near full-scale for three months continuously or six months cumulatively over a 12-month period[64].

5.2 Demonstration of multiple full-scale prototypes in a pre-commercial farm[65]

Demonstration of farms over a significant period (years, not months) is necessary to better understand the resource and the technology (eg the potential impact of array effects on energy output, the impact of large-scale energy extraction on the environment, and in turn the effects of environment on technology). Sufficient testing of multiple devices is required to establish the actual capital expense (taking into account benefits from economies of scale) and operation and maintenance costs of farms. Analysis of these results will enable cost assumptions and predicted learning rates to be validated. Subsequent increased learning should lead to improvements in design and better understanding of economics. This could help to estimate the future commercial cost of electricity with greater confidence.

[63] For the more specific technical barriers related to different types of ocean energy technology and a description of non-technical issues, refer to the recent IEA publication *Renewable Energy: RD&D Priorities, Insights from IEA Technology Programmes.*

[64] UK DTI Wave and Tidal Stream Energy Demonstration Scheme eligibility criteria: http://www.dti.gov.uk/files/file27895.doc

[65] It should be noted that for certain technologies, demonstration of multiple devices is not relevant. For example, large-scale systems that will not typically operate in arrays or farms, such as shoreline-based OWC, large-scale OTEC systems or salinity gradient systems.

Currently, private capital is unlikely to fund initial deployments due to the high risk of ocean energy technology and the high generation costs relative to other renewables. Consequently, market deployment support mechanisms are currently imperative to cover the cost gap and make initial deployment commercially viable.

5.3 Cost of grid connecting demonstration systems

The cost of connecting ocean energy systems to electricity networks impacts on demonstration projects. Typically, ocean energy resources are located offshore, away from population centres and, consequently, some distance from available network connections. Significant transmission infrastructure may be required for pilot systems. Potential upgrades of existing network systems may also be necessary to accommodate the increased capacities of pre-commercial arrays. The uncertainty and high risk of installation of this equipment, such as sub-sea cable or substations, in unpredictable marine environments may lead to unforeseen rises in project costs and increased uncertainties in cost estimates. Projects may become even less financially attractive to private investment when incorporating this capital expense.

This financial barrier has been addressed for demonstrations by the development of publicly funded ocean testing facilities offering grid connection and environmental permits for testing bays, such as EMEC (described in section 4.2). The principle of co-locating test projects which share grid infrastructure and thus reduce costs should be encouraged. For example, the proposed Wave Hub concept would provide *sockets* for several co-located pre-commercial wave farms. The advanced status of development in the UK (illustrated in section 2.3) reflects the success and highlights the importance of policies that fund grid infrastructure.

An alternative and perhaps more effective way to reduce the cost for single devices is to connect to the existing infrastructure of an offshore wind farm. For example, the Wave Star point absorber device plans to demonstrate a full-scale device in this way in agreement with a wind developer[66] in Denmark.

It is recognised that access to grid connections may be a significant barrier to wider deployment of ocean energy. The IEA-OES Implementing Agreement has run two expert meetings on the topic to date to support consideration of furthering research in the area.

5.4 Lack of understanding of the potential environmental impacts

Owing to insufficient demonstration of ocean energy technology, there remains a lack of understanding regarding the impacts on the environment. The likely impact of the marine environment on the technology, and the consequences of such an impact on design must also be established. The potential areas of concern that must be investigated are widely documented. For example, impacts on the environment could include oil leakage from engines, collision between devices and marine mammals, artificial reefs, or noise from power take-off systems. Alternatively, impacts on the technology from the environment might be caused by marine growth (eg algae, shells), seabirds nesting, corrosion or sedimentation flow.

[66] Source: Wave Star, 2006.

To overcome this barrier, further research is required (eg as proposed by the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop[67], sponsored by the US DOE). The UK DTI, under the auspices of the Research Advisory Group, will also commission independent research. Collaboration and dissemination of results from monitoring the impacts of demonstration projects are essential to gain more knowledge and improve understanding. Policies can help to encourage publication of this information. For example, the Crown Estate, which is responsible for allocating leases to project developers in the UK, stipulates that monitoring systems are in place during demonstration. This information will then be made available for consenting and permitting processes of future developments. Currently, the information is not available for permitting. Solutions such as the US approach of temporal waivers or the UK consenting guidelines for pre-commercial demonstration (described in section 3.4) are fundamental so that evidence can be gathered in the first place.

5.5 Lack of understanding of the ocean energy resource

Ocean energy technology development is still at a relatively immature stage. There is still much uncertainty surrounding how technology can be optimally designed to react within the marine environment and extract energy most efficiently. The various types of technology being pursued (described in section 2.4) illustrate the level of uncertainty. Further RD&D is required to identify optimum solutions.

5.6 Predicting energy production performance, metrics and design tools

Design simulation and prediction tools, based upon standard metrics, are needed by device developers to help them predict energy production performance. Device developers may know intuitively how their concept should perform in real sea conditions. However, they must provide energy production information to relevant stakeholders that accurately predicts device interaction with the marine environment. These predictions must also be validated through demonstration. Certified development tools are necessary so that all stakeholders, such as policy-makers, electricity system operators, investors and insurance brokers, can make rational decisions when evaluating technologies.

5.7 Absence of standards

The comparison of different technologies is made difficult by the absence of internationally recognised metrics or standards for development, testing and measurement. The absence of agreed testing standards and performance methodologies[68] means that it is difficult to validate predicted performance and costs against actual data obtained through testing. The variability of ocean wave and tidal currents introduces further complexities. For example, wave conditions during sea trials at particular test sites or at various timescales may be very different. Comparing energy production results for different devices may not indicate which is more effective. Standards must be valid across technologies and independent of test sites. At the same time, they need to be specific for different types of ocean energy system. The lack of comparability of data may also dissuade developers from releasing test results.

[57] The Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop, sponsored by the US Department of Energy, has recently identified the areas that need to be addressed prior to large-scale deployment of ocean energy systems.
http://hydropower.inl.gov/hydrokinetic_wave/

[58] A draft open sea testing standard was proposed by EMEC in 2003, however, several attempts to bring this forward have so far been unsuccessful. The IEA OES is keen to act as a communication platform to progress the development of internationally agreed standards and metrics.

The IEA is attempting to address this problem through collaborative research. In April 2006, the participating countries of the IEA OES agreed an agenda, under Annex 2 of the Implementing Agreement, to develop internationally recognised practices for testing and evaluating ocean energy systems and, in this way, improve the comparability of experimental results and help stakeholders evaluate and select suitable technologies.

6 SUMMARY AND CONCLUSIONS

6.1 Technology development

Ocean energy technologies are largely at the prototype-testing phase and have not yet penetrated global energy markets. This study has identified 81 individual concepts currently in development. These include 53 reported ocean wave technologies, 25 tidal current projects, one OTEC system and two salinity gradient concepts.

Ocean energy RD&D projects are in progress worldwide. The largest concentrations of RD&D projects are located in Europe and North America. The highest number of technologies being developed in a single country is in the United Kingdom, followed by the United States. There are a significant number of projects underway elsewhere, in particular, Canada, Norway, Denmark, Ireland and Portugal.

Ocean energy RD&D is growing. The number of projects more than doubled over the last three years. Most interesting has been the growth of tidal current RD&D, resulting in more than five times as many projects in 2006 than there were in 2003 (when the last IEA OES study that assessed the status of RD&D was undertaken).

The current development status of ocean energy technologies is varied. Twenty-two part-scale prototypes are being tested at sea and 13 prototypes are now undergoing demonstration at full-scale or near full-scale at sea. No device developer has yet completed a demonstration of multiple full-scale devices in an array or pre-commercial farm. One wave farm project is underway.

Several factors influence the location of RD&D. These include availability of the human resource and skills required, location of the appropriate R&D support facilities, and the availability of financial support for RD&D.

Wave energy technology is currently the most researched area and, in comparison with tidal current, is the most advanced ocean energy technology. However, tidal current energy RD&D has advanced significantly in recent years.

The wide range of wave devices being researched shows that the technology is far from producing an optimum solution. The level of understanding gained is not yet sufficiently developed to clearly show which concept is the more cost-effective. Tidal current RD&D appears to be closer to converging on an optimum solution (most devices are either horizontal-axis or vertical-axis turbines and a large proportion utilise pile-mounted fixings).

6.2 Policies

Several government RD&D programmes and government-funded organisations provide support for different types of ocean energy technology. Public funding is crucial to advance ocean energy research and reduce the technical risk to motivate greater involvement from the private sector. Partial public funding of demonstration projects is also necessary to reduce the risk of these projects and encourage private investment.

The increasing trend in the number of projects and the recent launch of dedicated RD&D schemes and support mechanisms indicate that government expenditure will increase provided RD&D objectives are met.

Several governments have proposed market deployment policies which provide support mechanisms for ocean energy, including Portugal (capital grants and a feed-in tariff), the UK (obligations, capital grants and guaranteed prices) and the US (tax credits). These policies are influencing RD&D in particular, promoting further demonstration.

Regulatory and administrative policies can accelerate the rate of technology deployment by streamlining consenting arrangements, clearly instructing developers how to secure permits for demonstration projects, and enabling information to be gathered to improve understanding (eg on environmental impacts) and so inform future decisions.

6.3 Support

There is a wide range of companies, institutions and organisations that support ocean energy RD&D and are actively helping the industry to develop. Of particular importance is the development of ocean testing facilities with grid infrastructure which is reducing the cost and risk of demonstration projects.

6.4 Barriers

Several technical and non-technical barriers are currently restricting development of ocean energy technologies. The immediate barrier is the lack of sufficient demonstration of prototypes in the marine environment to prove that technologies work as predicted.

The cost of connecting ocean energy systems to electricity networks impacts on demonstration projects. This financial barrier can be addressed for demonstration projects by publicly funded ocean testing facilities offering grid connection (and permits) for developers.

Owing to insufficient demonstration of ocean energy technology, there remains a lack of understanding regarding impacts on the environment. Collaborative research and dissemination of results from monitoring of demonstration projects is essential to gain more knowledge. Governments can help to encourage publication of this information.

The comparison of different technologies is made difficult by the absence of internationally recognised standards for development, testing and measurement. The IEA OES is attempting to recognise practices for testing and evaluating ocean energy systems.

6.5 Conclusions

Ocean energy technology could contribute to meeting cost-effective, sustainable and secure energy demands in the medium to long term provided governments and device developers act to overcome the barriers identified in this report and reduce the high cost and high risk associated with these technologies.

IEA governments should implement and continue policies that fund ocean energy RD&D to establish the most cost-effective, optimum solutions. This will allow stakeholders (including governments, developers, power utilities and private investors) to identify the technologies that best meet their needs.

Policies should: establish market support mechanisms, such as feed-in tariffs and guaranteed prices, to stimulate market deployment; help device developers benefit from greater industry learning and economies of scale; and motivate private investment.

Sufficient demonstration of ocean energy technology is vital to ensure that RD&D progresses to the pre-commercial stage of deploying multiple-device arrays at sea.

Developers should: demonstrate their devices for a significant period of time to establish actual device performance and costs of electricity generation; prove availability, reliability and survivability of concepts; and demonstrate this by publishing results.

Responsibility lies with governments to implement measures, as identified in this report, to streamline the demonstration process and encourage device developers to demonstrate their concepts successfully.

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8 ABBREVIATIONS

CA-OE	Coordinated Action on Ocean Energy
CAD	Canadian Dollars
CT	Carbon Trust
DEA	Danish Energy Agency
DOE	US Department of Energy (US)
DTI	Department of Trade and Industry (UK)
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EU	European Union
EUR	Euros
FERC	Federal Energy Regulatory Commission
FOEWG	Federal Ocean Energy Working Group
FP	Framework Programme
FP6	Framework Programme Six
FP7	Framework Programme Seven
GBP	British Pounds
GW	Gigawatt
IEA	International Energy Agency
IEA OES	International Energy Agency's Ocean Energy Systems
INETI	Instituto Nacional de Engenharia Tecnologia e Inovação
JRC	Joint Research Centre
KORDI	Korea Ocean Research and Development Institute
kWh	Kilowatts per hour
MMS	Materials Management Service
MRDF	Marine Renewables Deployment Fund
MW	Megawatt
OPD	Ocean Power Delivery Ltd
OPT	Ocean Power Technologies Inc
OREC	Ocean Renewable Energy Coalition
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column
OWSC	Oscillating Wave Surge Converter
PSO	Public Service Obligation
PTC	Production Tax Credit
RES	Renewable Energy Systems
R&D	Research and Development
RD&D	Research, Development and Demonstration
ROC	Renewables Obligation Certificate
SEA	Strategic Environmental Assessment
SEEWEC	Sustainable Economically Efficient Wave Energy Converter
SME	Small-to-Medium Enterprise
SEI	Sustainable Energy Ireland
UK	United Kingdom
UNIDO	United Nations Industrial Development Organization
USD	United States Dollars
US	United States

9 ANNEX – OCEAN ENERGY TECHNOLOGIES CURRENTLY IN DEVELOPMENT

Location of RD&D - Country	Technology	Lead organisation	Energy type	Technology type	Fixing method
Australia	Denniss-Auld Turbine	Energetech America LLC	Ocean Wave	OWC	Fixed
Australia	bioWave	BioPower Systems Pty Ltd	Ocean Wave	Other	Fixed
Australia	bioStream	BioPower Systems Pty Ltd	Tidal Current	Other	Fixed
Australia	CETO	Seapower Pacific Pty Ltd	Ocean Wave	Submerged pressure differential	Fixed
Canada	SieWave	Sieber Energy Inc	Ocean Wave	Point absorber	Floating, flexible mooring
Canada	Wavemill	Wavemill Energy Corp	Ocean Wave	OWSC	Fixed
Canada	Waveberg	Waveberg Development	Ocean Wave	Attenuator	Floating, flexible mooring
Canada	Wave Powered Pump	College of the North Atlantic	Ocean Wave	Point absorber	Submerged
Canada	Davis Hydro Turbine	Blue Energy Canada	Tidal Current	Vertical-axis turbine	Gravity base
Canada	Clean Current Tidal Turbine	Clean Current Power Systems Inc	Tidal Current	Horizontal-axis turbine	Pile mounted
Canada	EnCurrent Vertical Axis Hydro Turbine	New Energy Corp	Tidal Current	Vertical-axis turbine	Gravity base
Denmark	Wave Dragon	Wave Dragon ApS, KP Renewables	Ocean Wave	Overtopping	Floating, flexible mooring
Denmark	WavePlane	WavePlane Production A/S, Caley Ocean Systems Ltd	Ocean Wave	Collector	Floating, rigid mooring
Denmark	Wave Star	Wave Star Energy ApS	Ocean Wave	Point absorber	Fixed
European Union	Sustainable Economically Efficient Wave Energy Converter (SEEWEC)	Fred Olsen, Ghent University	Ocean Wave	Point absorber	Floating, rigid mooring
Finland	Waveroller	AW-Energy Oy	Ocean Wave	OWSC	Submerged
France	SEAREV	Laboratoire de mécanique des fluides – CNRS UMR 6598, Ecole Centrale de Nantes	Ocean Wave	Other	Floating, flexible mooring
France	Hydroliennes en mer	EDF	Tidal Current	Vertical-axis turbine	Not described
Greece	Wave Energy Conversion Activator (WECA)	Daedalus Informatics Ltd	Ocean Wave	OWC	Fixed
Ireland	McCabe Wave Pump	Hydam Technology	Ocean Wave	Attenuator	Fixed

Depth	RD&D status	URL	Contact
Nearshore	Full-scale prototype demonstration – single device at sea	http://www.energetech.com.au/	eneamerica@energetech.com.au
Offshore	Concept design	http://www.biopowersystems.com/	info@biopowersystems.com
Offshore	Concept design	http://www.biopowersystems.com/	info@biopowersystems.com
Nearshore	Part-scale model testing – sea trials	http://www.seapowerpacific.com	info@seapowerpacific.com
Offshore	Detailed design	http://www.sieberenergy.com/	info@sieberenergy.com nigel@sieberenergy.com
Nearshore	Part-scale model testing – sea trials	http://www.wavemill.com/	http://www.wavemill.com/ contactus.htm
Nearshore	Part-scale model testing – sea trials	www.waveberg.com	http://www.waveberg.com/ wavenergy/contact.htm
Nearshore	Part-scale model testing – tank testing	http://www.cna.nl.ca/	Not found
Nearshore	Part-scale model testing – sea trials	http://www.bluenergy.com/	Blue Energy President and CEO Martin Burger: mjb@bluenergy.com
Offshore	Part-scale model testing – sea trials	http://www.cleancurrent.com/	Not found (Web site not properly listed)
Nearshore	Part-scale model testing – sea trials	http://www.newenergycorp.ca/	info@newenergycorp.ca. Clayton.bear@newenergycorp.com
Offshore	Part-scale model testing – sea trials	http://www.wavedragon.net, www.wavedragon.co.uk	info@wavedragon.net/
Offshore	Part-scale model testing – sea trials	www.waveplane.com	es@waveplane.com
Nearshore	Part-scale model testing – sea trials	http://www.wavestarenergy.com/	info@WaveStarEnergy.com
Offshore	Part-scale model testing – sea trials	http://www.fp6.eurocean.org/record.jsp?open=170&a =1144149743690	nathalie.rousseau@ugent.be
Nearshore	Part-scale model testing – sea trials	http://www.aw-energy.com/	info@aw-energy.com
Nearshore	Concept design	http://www.eurogif.org/wimages/workshop_2_pres2.pdf	Alain.Clement@ec-nantes.fr
Not described	Concept design	http://www.edf.fr/259i/Homefr.html	Not found
Shoreline	Concept design	http://www.daedalus.gr/DAEI/PRODUCTS/RET/General/ RETWW1.html	daedalushq@mail.daedalus.gr
Nearshore	Part-scale model testing – sea trials	http://www.wave-power.com/	Web site not working properly

Location of RD&D - Country	Technology	Lead organisation	Energy type	Technology type	Fixing method
Ireland	Wavebob	Wavebob Ltd, Clearpower Technology Ltd	Ocean Wave	Point absorber	Floating, flexible mooring
Ireland	Ocean Energy Buoy (OE Buoy)	Ocean Energy Limited	Ocean Wave	OWC	Floating, rigid mooring
Ireland	Open-Center Turbine	Open Hydro Group	Tidal Current	Horizontal-axis turbine	Flexible mooring
Italy	Kobold turbine [Enermar]	Ponte di Archimede SpA	Tidal Current	Vertical-axis turbine	Attached to floating structure
Japan	OTEC Device	The Institute of Ocean Energy	OTEC	Thermo-dynamic Rankine cycle	Floating, rigid mooring
Netherlands	Wave Rotor	EcoFys	Ocean Wave	Other	Pile mounted
Norway	Controlled Wave Energy Converter (CONWEC)	Brodrene Langset AS, & Department of Physics of the Norwegian University of Science & Technology	Ocean Wave	Point absorber	Floating, rigid mooring
Norway	Seawave slot-cone generator (WAVESSG)	WAVEenergy AS, Fred Olsen	Ocean Wave	Overtopping	Floating, rigid mooring
Norway	Statkraft	Statkraft, SINTEF	Salinity Gradient		Floating vessel
Norway	Tidevanndkraft	Statkraft, Hydro Tidal Energy Technology (HTET)	Tidal Current	Horizontal-axis turbine	
Norway	The Blue Concept	Hammerfest STRØM AS	Tidal Current	Horizontal-axis turbine	Pile mounted
Norway	Harmonica Model	Tidal Sails AS, University of Hertfordshire	Tidal Current	Other	
Portugal	Foz do Douro breakwater	Energias de Portugal (EDP)	Ocean Wave	OWC	OWC
Portugal	ONDA 1	Martifer Energia	Ocean Wave	Attenuator	Floating, flexible mooring
Portugal	Pico OWC	Instituto Superior Técnico, Wave Energy Centre	Ocean Wave	OWC	OWC
Spain	OWC	Unión Eléctrica Fenosa of Spain	Ocean Wave	OWC	Fixed
Sweden	Wave Power Project Islandsberg	Swedish Centre for Renewable Electric Energy Conversion, Uppsala University, Vattenfall AB	Ocean Wave	Point absorber	Fixed
Sweden	Floating Wave Power Vessel	Sea Power International AB	Ocean Wave	Collector	Floating, flexible mooring
United Kingdom	Wave power device	Neptune Renewable Energy Limited	Ocean Wave	Other	Not described
United Kingdom	Manchester Bobber	UMIST	Ocean Wave	Point absorber	
United Kingdom	Pulse Generation	IT Power Ltd	Tidal Current	Oscillating hydrofoil	Fixed

Depth	RD&D status	URL	Contact
Offshore	Part-scale model testing – tank testing	http://www.sei.ie/index.asp?locID=344&docID=-1	william.dick@clearpower.ie
Offshore	Part-scale model testing – sea trials		oceanenergy@dol.ie
Offshore	Part-scale model testing – sea trials	http://www.gtsav.gatech.edu/outreach/workshop/presentations/mhoover.pdf	Not found
Nearshore	Part-scale model testing – sea trials	http://www.pontediarchimede.it/	http://www.pontediarchimede.it/language_us/contatti.mvd
Offshore	Full-scale prototype demonstration – single device at sea	Not found	Not found
Offshore	Concept design	http://www.ecofys.co.uk/	info@ecofys.co.uk
Not described	Concept design	http://www.phys.ntnu.no/instdef/prosjekter/bolgeenergi/index-e.html	conwec@iname.com johannes.falnes@phys.ntnu.no
Nearshore OR Offshore	Full-scale prototype demonstration – single device at sea	http://www.waveenergy.no/	espen.osaland@waveenergy.no
	Part-scale model testing – sea trials	http://www.statkraft.com/pub/innovation/Features/Salty_dreams.asp	
	Concept design	http://www.statkraft.no/pub/annen_miljovanlig/tidevannskraft/index.asp	
Offshore	Full-scale prototype demonstration – single device at sea	http://www.e-tidevannsenergi.com/index.htm	http://www.e-tidevannsenergi.com/index.htm
	Concept design		info@tidalsails.com
Shoreline	Full-scale prototype demonstration – single device at sea	http://hidrox.ist.utl.pt/doc_fct/FozDouro.pdf	Joaogoncalo.maciel@edp.pt
Offshore	Part-scale model testing – tank testing		marc.hadden@martifer.pt
Shoreline	Full-scale prototype demonstration – single device at sea	www.pico-owc.net http://hidrox.ist.utl.pt/doc_fct/PicoOWC.pdf	frank@wave-energy-centre.org falcao@hidro1.ist.utl.pt
Nearshore	Part-scale model testing – tank testing	http://www.unionfenosa.es/webuf/ShowContent.do	Not found
Offshore	Full-scale prototype demonstration – single device at sea	http://www.el.angstrom.uu.se/meny/eng/index_E.html	Mats.Leijon@angstrom.uu.se
Nearshore	Part-scale model testing – sea trials	http://www.seapower.se/English.htm	contact@seapower.se
Nearshore	Concept design	www.patent.gov.uk/patent/notices/journals/2006/6093.pdf	None
Nearshore	Concept design	No Web site	p.k.stansby@umist.ac.uk
Offshore	Concept design	www.itpower.co.uk	hutaylor@itpower.co.uk

Location of RD&D - Country	Technology	Lead organisation	Energy type	Technology type	Fixing method
United Kingdom	Gentec Venturi	Greenheat Systems Ltd	Tidal Current	Venturi	Not described
United Kingdom	TidalStream	TidalStream	Tidal Current	Horizontal-axis turbine	Pile mounted
United Kingdom	Tidal turbine	Tidal Generation Ltd	Tidal Current	Horizontal-axis turbine	Pile mounted
United Kingdom	Swan Turbines	Swan Turbines, Swansea University	Tidal Current	Horizontal-axis turbine	Pile mounted
United Kingdom	Vertical-axis, variable pitch tidal turbine	Edinburgh Designs	Tidal Current	Vertical-axis turbine	Flexible mooring
United Kingdom	SPERBOY	Embley Energy Ltd	Ocean Wave	OWC	Fixed
United Kingdom	PS Frog	Lancaster University	Ocean Wave	Point absorber	Floating, flexible mooring
United Kingdom	WaveMaster	Ocean WaveMaster Ltd (OWL)	Ocean Wave	Submerged pressure differential	Floating, flexible mooring
United Kingdom	Edinburgh sloped buoy	University of Edinburgh	Ocean Wave	Point absorber	Fixed
United Kingdom	OWEL Energy Convertor	Offshore Wave Energy Ltd	Ocean Wave	OWC	Fixed
United Kingdom	Breakwater power takeoff modules	Wavegen (a Voith and Siemens company)	Ocean Wave	OWC	Fixed
United Kingdom	Pelamis	Ocean Power Delivery Ltd	Ocean Wave	Attenuator	Floating, flexible mooring
United Kingdom	Nearshore OWC	Wavegen (a Voith and Siemens company)	Ocean Wave	OWC	Fixed
United Kingdom	Archimedes Wave Swing (AWS)	AWS Ocean Energy Ltd	Ocean Wave	Point absorber	Floating, flexible mooring
United Kingdom	Seagen	Marine Current Turbines Ltd, EDF	Tidal Current	Horizontal-axis turbine	Pile mounted
United Kingdom	Seaflow	Marine Current Turbines Ltd	Tidal Current	Horizontal-axis turbine	Pile mounted
United Kingdom	MRC 1000	Orecon Ltd	Ocean Wave	OWC	Fixed
United Kingdom	AquaBuOY	AquaEnergy Development UK Ltd	Ocean Wave	Point absorber	Fixed
United Kingdom	HydroVenturi	HydroVenturi Ltd / Imperial	Tidal Current	Venturi	Not described
United Kingdom	TidEL	SMD Hydrovision	Tidal Current	Horizontal-axis turbine	Floating, flexible mooring
United Kingdom	Oyster	AquaMarine Power Ltd	Ocean Wave	OWSC	Fixed
United Kingdom	Wave Rider	SeaVolt Ltd	Ocean Wave	Point absorber	Floating, rigid structure, OR Fixed
United Kingdom	The Linear Generator	Trident Energy Ltd, Direct Thrust Designs Ltd	Ocean Wave	Point absorber	Fixed

Depth	RD&D status	URL	Contact
Not described	Concept design	http://www.greenheating.com	solutions@greenheating.com
Offshore	Concept design	http://www.teleos.co.uk/Home.htm	info@tidalstream.co.uk
Offshore	Concept design	http://www.tidalgeneration.co.uk	info@tidalgeneration.co.uk
Offshore	Concept design	http://swanturbines.co.uk/	enquiries@swanturbines.co.uk
Not described	Concept design	http://www.edesign.co.uk/	edesign@edesign.co.uk
Offshore	Detailed design	http://www.plymouth.ac.uk/pages/view.asp?page=3109	lyn.stott@plymouth.ac.uk
Offshore	Detailed design	http://www.engineering.lancs.ac.uk/REGROUPS/LUREG/Wave/Wave_Current_Research.htm	g.aggidis@lancaster.ac.uk n.baker@lancaster.ac.uk
Offshore	Detailed design	http://www.oceanwavemaster.com	enquiries@oceanwavemaster.com
Offshore	Detailed design	http://www.mech.ed.ac.uk/research/wavepower/sloped%20IPS/Sloped%20IPS%20intro.htm http://www.mech.ed.ac.uk/research/wavepower/index.html	Robin.Wallace@ed.ac.uk S.Salter@ed.ac.uk
Offshore	Detailed design	http://www.owel.co.uk/	owel@sycamore.org.uk
Shoreline	Detailed design	http://www.wavegen.co.uk/	david.gibb@wavegen.com
Offshore	Full-scale prototype demonstration – multiple devices at sea	www.oceanpd.com	enquiries@oceanpd.com
Shoreline	Full-scale prototype demonstration – single device at sea	http://www.wavegen.co.uk/	david.gibb@wavegen.com
Nearshore	Full-scale prototype demonstration – single device at sea	http://www.awsocean.com/	info@awsocean.com
Offshore	Full-scale prototype demonstration – single device at sea	http://www.marineturbines.com/home.htm	sylvie.head@marineturbines.com
Offshore	Full-scale prototype demonstration – single device at sea	http://www.marineturbines.com/home.htm	sylvie.head@marineturbines.com
Offshore	Part-scale model testing – sea trials	http://www.orecon.com/	contact@orecon.com
Offshore	Part-scale model testing – sea trials	www.aquaenergygroup.com	aqua@aeg-ltd.com
Not described	Part-scale model testing – sea trials	http://www.hydroventuri.com	jdenavarro@hydroventuri.com
Offshore	Part-scale model testing – sea trials	www.smdhydrovision.com	http://www.smdhydrovision.com/contact/?person_id=1
Nearshore	Part-scale model testing – tank testing	http://www.aquamarinepower.com/	Not yet added to Web site
Offshore	Part-scale model testing – tank testing	www.seavolt.com	info@seavolt.com
Nearshore	Part-scale model testing – tank testing	http://www.tridentenergy.co.uk	info@tridentenergy.co.uk

Location of RD&D - Country	Technology	Lead organisation	Energy type	Technology type	Fixing method
United Kingdom	TETRON	Joules Energy Efficiency Services Ltd	Ocean Wave	Other	
United Kingdom	Contra-rotating marine current turbine	University of Strathclyde	Tidal Current	Horizontal-axis turbine	Rigid mooring
United Kingdom	Rotech Tidal Turbines (including RTT1000)	Lunar Energy	Tidal Current	Horizontal-axis turbine	Gravity base
United States	WaveBlanket	WindWavesAnd Sun	Ocean Wave	Overtopping	Floating, rigid mooring
United States	OMI Combined Energy System	Ocean Motion International	Ocean Wave	Point absorber	Fixed
United States	OSU “direct-drive” Buoy	Oregon State University	Ocean Wave	Point absorber	Fixed
United States	PowerBuoy	Ocean Power Technologies Inc	Ocean Wave	Point absorber	Fixed
United States	Greenwave Energetech OWC	Energetech America LLC	Ocean Wave	OWC	Fixed
United States	The Underwater Electric Kite (UEK System)	UEK Corporation, Annapolis Maryland (USA)	Tidal Current	Horizontal-axis turbine	Flexible mooring
United States	Verdant Power: Kinetic Hydro Power System (KHPS)	Verdant Power, LLC	Tidal Current	Horizontal-axis turbine	Pile mounted
United States	AquaBuOY	Aqua Energy Inc, AquaEnergy Development UK Ltd, Ramboll	Ocean Wave	Point absorber	Fixed
United States	The Gorlov Helical Turbine	GCK	Tidal Current	Vertical-axis turbine	Pile mounted
United States	Electricity Generating Wave Pipe	Able Technologies LLC	Ocean Wave	Point absorber	Fixed
United States	SEADOG Pump	Independent Natural Resources Inc	Ocean Wave	Point absorber	Not described
United States	OWEC Ocean Wave Energy Converter	P. Foerd Ames, of Ocean Wave Energy Company	Ocean Wave	Point absorber	Fixed
United States	Ocean Wave Energy Conversion System	Sara Ltd	Ocean Wave	Point absorber	Rigid mooring

Depth	RD&D status	URL	Contact
	Part-scale model testing – tank testing	No Web site	No Web site
Not described	Part-scale model testing – tank testing	http://www.na-me.ac.uk/index_2.htm	d.vassalos@na-me.ac.uk
Offshore	Part-scale model testing – tank testing	www.lunarenergy.co.uk	info@lunarenergy.co.uk
Nearshore	Concept design	http://www.windwavesandsun.com/	Ben@WindWavesandSun.com (Benjamin Gatti)
Nearshore	Concept design	http://www.oceanmotion.ws	garysomi@sbcglobal.net
Offshore	Concept design	http://energycentral.fileburst.com/EnergyBizOnline/ 2005-2-mar-apr/Wave%20Power%20March_April_05-6.pdf	avj@eecs.oregonstate.edu
Offshore	Full-scale prototype demonstration – single device at sea	www.oceanpowertechnologies.com	info@oceanpowertech.com
Nearshore	Full-scale prototype demonstration – single device at sea	http://www.energetech.com.au/	eneamerica@energetech.com.au
Offshore	Full-scale prototype demonstration – single device at sea	http://uekus.com/	info@uekus.com
Offshore	Full-scale prototype demonstration – single device at sea	http://www.vedantpower.com/	rsmith@verdantpower.com (CEO)
Offshore	Part-scale model testing – sea trials	www.aquaenergygroup.com	aqua@aeg-ltd.com
Not described	Part-scale model testing – sea trials	http://www.gcktechnology.com/GCK/pg2.html	kurth@gcktechnology.com
Offshore	Part-scale model testing – tank testing	http://www.abletechnologiesllc.com/	srutta@yahoo.com
Offshore	Part-scale model testing – tank testing	http://www.inri.us/	mark@inri.us
Nearshore	Part-scale model testing – tank testing	http://www.owec.com/	foerd@owec.com
	Part-scale model testing – tank testing	http://www.sara.com/energy/WEC.html	info@sara.com

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